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Optimization of CT protocol in polytrauma patients: an update

F. FLAMMIA[1], G. CHITI[1], M. TRINCI[2], G. DANTI[1,3], D. COZZI[1,3], R. GRASSI[4], P. PALUMBO[3,5], F. BRUNO[3,6], A. AGOSTINI[7,8], R. FUSCO[9], V. GRANATA[10], A. GIOVAGNONI[7,8], V. MIELE[1]

[1]Department of Radiology, Azienda Ospedaliero-Universitaria Careggi, Florence, Italy
[2]Department of Radiology, Azienda Ospedaliera San Camillo Forlanini, Rome, Italy
[3]Italian Society of Medical and Interventional Radiology (SIRM), SIRM Foundation, Milan, Italy
[4]Division of Radiology, "Università degli Studi della Campania Luigi Vanvitelli", Naples, Italy
[5]Department of Diagnostic Imaging, Area of Cardiovascular and Interventional Imaging, L'Aquila, Italy
[6]Department of Applied Clinical Sciences and Biotechnology, University of L'Aquila, L'Aquila, Italy
[7]Department of Clinical, Special and Dental Sciences, University Politecnica delle Marche, Ancona, Italy
[8]Department of Radiology, University Hospital "Umberto I - Lancisi - Salesi, Ancona, Italy
[9]Medical Oncology Division, Igea SpA, Naples, Italy
[10]Division of Radiology, "Istituto Nazionale Tumori IRCCS Fondazione Pascale – IRCCS di Napoli", Naples, Italy

Abstract. – Radiologists play a key role in the management of trauma patients. With the improvement of computed tomography (CT), radiologist makes an important contribution to the timely diagnosis of trauma-related findings and the choice of the most suitable treatment, improving patient outcomes. It is important to select the most appropriate imaging technique, which in the trauma patient is CT, and especially the most appropriate CT protocol, to correctly characterize trauma injuries. Currently, there is no agreement on what the optimal protocol is, acquisition times and number of contrast enhanced phases are not standardized. This is a review of the most recent literature on optimizing the CT protocol in polytrauma, with the intent of giving a useful tool for radiologists in the management of trauma patients.

Key Words:
Polytrauma, Computed tomography, Whole body CT, Dual energy CT.

Introduction

Trauma is the leading cause of death in young patients (under age 45)[1]. Injury-related death has a trimodal distribution with three peaks occurring almost immediately, within minutes or hours or within days after the accident for the first, second and third peak respectively. The trauma team is called for a rapid assessment especially in the second peak, defined as the golden hour, where death is commonly caused by subdural and epidural hematomas, hemopneumothorax, ruptured spleen, lacerations of the liver and pelvic fractures[1]. Therefore, trauma management should be time-saving and focused on first resolving potentially life-threatening injuries. The trauma team should firstly identify life-threatening injuries or hemodynamically unstable patients, according to vital parameters and then classify them as polytrauma or non-polytrauma, based on the physiological state of the patient, number and region of injuries and the accident mechanism. Cofactors such as age, comorbidity, anticoagulant therapy, and pregnancy should be taken into account[2]. This categorization determines the next steps to be taken and the choice of which imaging exams to perform. According to the tenth edition Advanced Trauma Life Support (ATLS), trauma/polytrauma management includes a physical examination first along with a focused assessment with trauma sonography (FAST), then X-rays (cervical, thoracic, and pelvic), and eventual Computed Tomography (CT)[1,3,4]. The ATLS recommends CT only if indicated, not by default, and selective of specific body regions[1]. In contrast, the latest guidelines of the European

Corresponding Author: Roberta Fusco, MD; e-mail: r.fusco@igeamedical.com

Society of Emergency Radiology (ESER) published in 2020, distinguish the category of 'polytrauma' (high-energy trauma) from 'non-polytrauma' (non-severe trauma), and differentiate their approaches. According to the ESER trauma management algorithm, in "non-polytrauma" the approach proposed by ATLS is recommended, while in "polytrauma" whole-body CT should be performed[5]. Standards for a polytrauma service are a CT distance to the Emergency Trauma Room less than 50 m and usage of at least 64 rows CTs[5-7]. An immediate interpretation on first images available should be performed followed by a reassessment on the final images reconstructed at least in the three standard planes[5,7]. Post-processing reconstructions (such as three-dimensional (3D) multiplanar reconstructions (MPR) and volume rendering reconstructions) can be helpful in identifying and characterizing the location of some trauma-related injuries, such as vascular, skeletal etc.[8-11] (Figure 1). Finally, a different radiologist should revaluate images within 24 h. Currently, there is no agreement on what the optimal CT-protocol is. Below we are going to analyze the most applied protocols.

Whole-Body CT (WBCT) vs. Selected Computed Tomography (SCT)

Whole-Body CT (WBCT) consists of scans of the head (including facial skeleton), neck, chest, and abdomen/pelvis[12]; when possible, a 'feet first' patients' position is preferred. While Selected CT (SCT) consists of scans of specific regions of the body. The ESER guideline recommends SCT on non-polytrauma patients[5]. In SCT approach, involving ATLS, the decision on regions to be

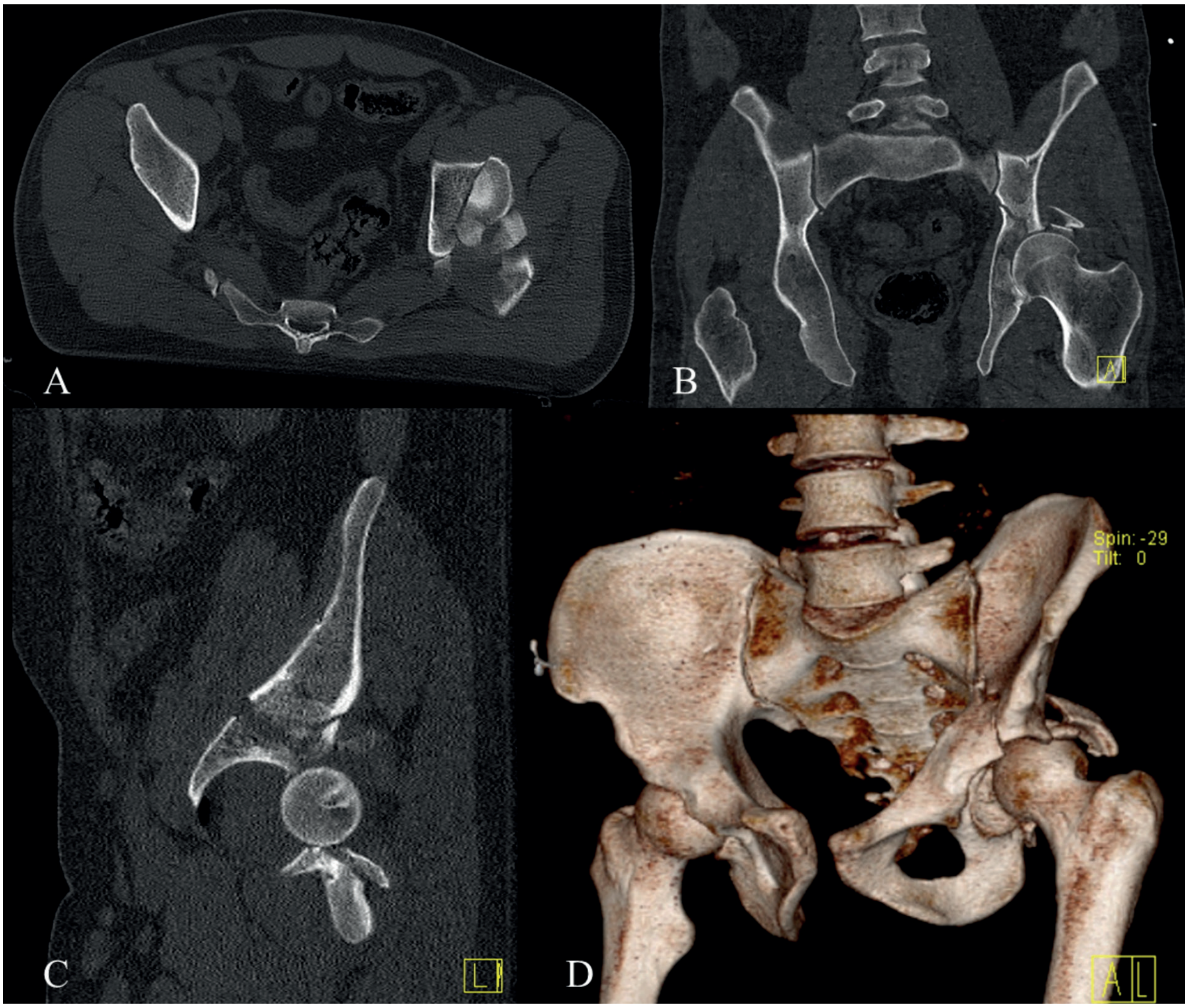

Figure 1. Pelvis fracture in a 50-year-old man after road accident. **A-C**, MPR and (**D**) VRT showing displaced fracture along left posterior-superior acetabulum with posterior dislocation of the left femoral head.

scanned is left to the physicians and based on previous clinical/instrumental evaluations, which should therefore be scrupulous and timely[1,13]. One of the disadvantages of this approach could be that the trauma leader's judgment is considered by some to be a subjective judgment[14]. Moreover, in the context of polytrauma, it may be more difficult to clinically suspect all trauma-related injuries, with the risk of not investigating and, therefore, not diagnosing some of them[15]. This risk is reduced in the case of the WBCT approach. Another disadvantage is the increased time involved in the SCT approach, mainly due to the time required to perform planned X-Rays and the consequent re-evaluation time and likely additional examinations involved. In the WBCT approach, it is useful to also evaluate CT scout, so as to avoid chest radiography[16]; moreover, it can provide useful information to choose the contrast phases and to identify other injured regions of the body to be scanned[12]. So, in case of multiple injuries, such as may occur in major trauma, the WBCT is time-saving[17]. On the other hand, the main debate about the WBCT is the patient's increased radiation dose exposure[18], mainly because the risk of radiation-induced cancer is higher in young patients, who are the most involved in severe trauma[19]. There are still not enough studies showing a clear significant difference in the reduction of mortality and morbidity of WBCT compared to SCT. In a recent multi-center study by Treskes et al[17] immediate WBCT and SCT scanning in 1083 severely injured patients were compared[17]. In trauma patients requiring emergency bleeding control interventions WBCT yielded an absolute risk reduction of 11.2% without a significant time to bleeding control intervention reduction. According to the S3-guideline of the German Society for Trauma Surgery (Deutsche Gesellschaft für Unfallchirurgie, DGU), WBCT is not recommended for all trauma patients[5]. In this latest edition, the indications for WBCT are suggested, and they are altered vital signs (consciousness, breathing, circulatory system), dynamics of the traumatic event and at least two relevant damaged body regions[5,20,21].

Contrast Phase: Timing Acquisition and Number of Phases (Advantages and Disadvantages of Different CT Imaging Protocol)

Currently, acquisition times and number of contrast-enhanced phases are not standardized; and there is no agreement on what the optimal protocol is. The choice of contrast medium protocol is the responsibility of the radiologist, who should quickly select the best one to highlight trauma-related injuries with the best image quality and lowest radiation dose[14]. The most used contrast enhanced protocols are described below.

Monophasic CT Protocols

In the monophasic protocol, a non-enhanced scan of the head is performed first followed by a single enhanced scan of the neck, chest, abdomen and pelvis[22]. The contrast-enhanced scan may start after a delay ranging from 60s to 85s after the intravenous injection of the contrast medium. The acquisition delay is determined mainly by the infusion rate: the higher the infusion rate is, the earlier the scan should be acquired. This results in a venous phase scan[23] (Figure 2). The advantage of this protocol is the high speed of execution, but it may miss some findings especially vascular ones. In trauma it is important to identify findings such as lesions and arterial dissections, which can be life-threatening, and are best shown in the arterial phase.

Split Bolus CT Protocol

The split-bolus protocol also consists of a single enhanced scan, like the monophasic one. However, this involves the intravenous injection of two or three boluses of contrast medium, instead of only one as in the monophasic protocol[24]. The split-bolus consists of infusion of two boluses of half contrast medium quantity each (e.g., first 60 ml and then another 60 ml), within an interval of about 40-45s. Then the scan is ac-

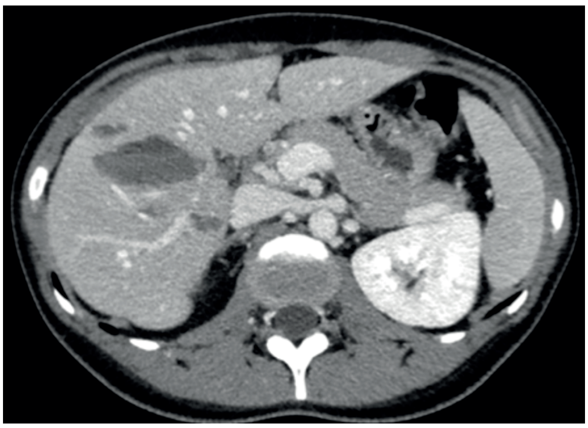

Figure 2. Monophasic axial venous CT scan in a female age 29 after a road traffic injury within a negative e-FAST. In the parenchymal venous phase there is a large contusion in the VIII hepatic segment.

quired after 60-70s, resulting in a combination of arterial and venous phases. Compared to monophasic, split-bolus images demonstrated a better organ enhancement, with improved recognition of parenchymal lesions[25]. Nevertheless, vascular findings may not be evident and this represents a strong disadvantage of this protocol. The aim of the split-bolus protocol is to reduce radiation dose and acquisition time, at the cost of images with a lower diagnostic power than multiphase protocol. In a study by Leung et al[26] and Compagnone et al[27] the radiation dose and vascular enhancement of seventy-eight split bolus protocol to seventy-one traditional two phases protocol were compared; results showed a 43.5% reduction in the mean dose length product (DLP) for the split-bolus protocol, that was statistically significant, both protocols demonstrated a mean aortic enhancement greater than 250 HU.

Multiphasic CT Protocol

With the multiphasic protocol, at least two scans are acquired after administration of a single bolus of contrast medium, one of the arterial and one of the venous phase. Enhanced scans include the circle of Willis, neck, chest, abdomen including the pelvis. The dose of contrast medium is calculated according to the weight of the patient (100-120 mL), in sequence a bolus of about 40 mL of physiological solution is recommended, both at a rate of 3.5-4 mL/s[28,29]. The acquisition times can be set manually (30-35 s for the arterial phase, 60-70 s for the venous phase), or more preferred automatically with the bolus tracking of the arterial phase and a delay of 60-70 s from the injection of contrast medium for the venous phase[28,30]. If bolus tracking is possible, the scan is acquired when a density of 100 HU is perceived at the aortic arch (where the ROI is located at the beginning)[28,30,31]. This is certainly the most suitable protocol for showing vascular lesions and bleeding. The arterial phase allows the integrity of the arterial vascular system and the arterial origin of a bleed to be assessed[8,17,32]. The venous phase shows the enhancement of organ parenchyma and the amount of bleeding. Therefore, it has the great advantage of differentiating lesions with contained bleeding from those with active bleeding, which is crucial for subsequent treatment and patient management[7,33] (Figure 3). In addition to this feature, the multiphase protocol with multiple scans also reduces the discomfort of motion artifacts. The cost to be paid, however, is the radiation dose to the patient, which is certainly much higher than with the monophasic and split-bolus protocol[23,25,34].

TIME Protocol DOSE Protocol

The main debate about the WBCT is about patient dose exposure[26,34,35]. Therefore, an attempt was made to resolve this issue by outlining two different optimized protocols, also recommended by the ESER, according to vital parameters: TIME protocol (TP) for hemodynamically unstable patients, and DOSE protocol (DP) for patients with stable vital parameters[36]. DP enables the lowest possible radiation exposure (below 20 mSv) and consists of an unenhanced head scan, a

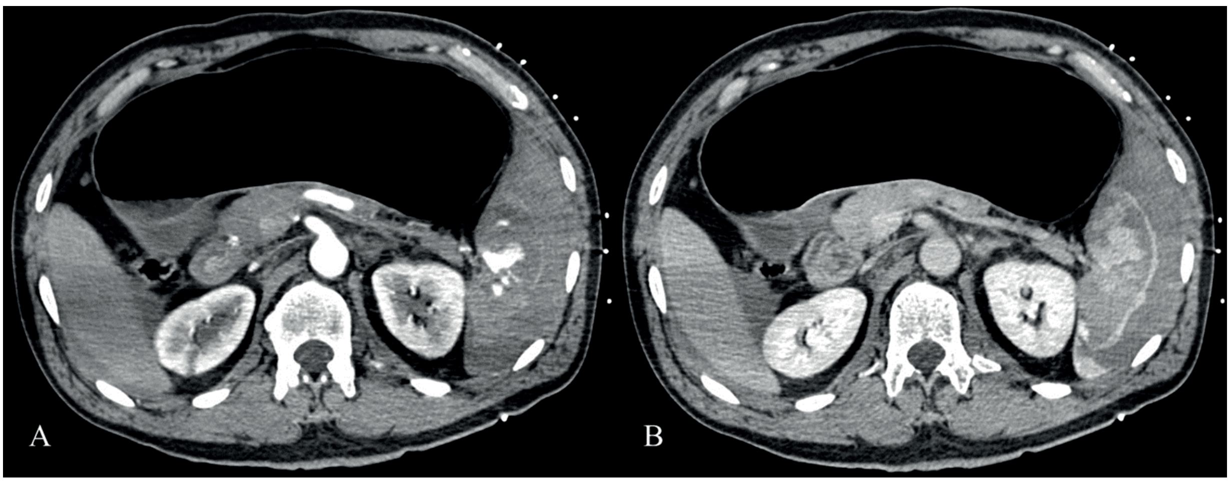

Figure 3. Polytrauma in a 44-year-old male on anticoagulant therapy with shuttered spleen and vascular injury, axial arterial and delayed imaging (**A**, **B**). Arterial phase (**A**) shows extravasation of contrast media which increases in size on delayed imaging (**B**).

Figure 4. CT scout film in a polytrauma unstable patient.

low-dose scan of the facial skeleton/neck/cervical spine (with or without contrast enhancement), after which the arms are elevated and the chest/abdomen and pelvis are scanned using the split bolus (thus obtaining a mixed arterial/venous contrast of the vessels and organs)[5,36]. In presence of unclear findings, another CT scan is recommended[5]. In contrast, the "Time/Precision Protocol" (optimized for time-saving and high diagnostic accuracy for detection of life-threatening injuries) consists of multiphase scans, both arterial and venous phase, for more sensitive detection of active bleeding[5,36]. To save additional time, the arms should be placed on the trunk throughout the whole-body scan[36,37]. In a recent retrospective study of 308 patients, Reske et al[38] analyzed the difference in examination time (ET, min), image noise (IN), and effective dose (E, mSv) of three WBCT protocols (old, time and dose protocols). For the Old and the Time Protocols (OP and TP) consisted on a whole-body scout followed by an unenhanced scan of the head and neck and a post-contrast scan of the rest of the body was performed (Figure 4). A revised automatic exposure system was applied to Time group[38]. For the Dose protocol (DP) the head/neck scout and unenhanced CT, performed with arms up position, was separate from the rest of the body, scanned after a 60 seconds delay after contrast-medium injection[38,39]. IN was significantly lower in DP than OP/TP. Nonetheless, DP showed a greater examination time (3.6 minutes longer than OP/TP); furthermore, DP yielded approximately 7 mSv reduction in effective radiation compared to TP (28.2 mSv and 35.4 mSv respectively) and a significantly better image quality[38] (Table I).

Special Protocols

CT – Angiography

There may be special cases where standard CT protocols need to be modified. In suspected arterial vessel injury, CT angiography (CTA) shows accurate visualization of the aorta and its branches, as well as surrounding structures[40,41]. CT angiography has high specificity (40–100%)

Table I. Characteristics of WBCT time and dose optimized protocol.

WBCT optimized protocol	Arms	Non-enhanced scan	Enhanced scan	Indication
Dose Protocol	Up	Facial skeleton, neck and cervical spine (low dose)	Split-bolus	Stable patients
Time protocol	Down	Head, neck and cervical spine	Multiphasic (at least arterial and portal venous phase)	Life-threatening injuries or hemodynamically unstable patients

and sensitivity (86-100%) in the study of arterial vessels injury and is indicated as the first choice examination[42-44]. For improved image quality it is important to minimize motion artifacts due to breathing and cardiac pulsations[45]. This can be obtained by acquiring the scan in inspiration (breath hold)[46]. If this is not allowed by the patient's clinical condition, ECG (electrocardiogram)-controlled computed tomography scan is useful, as it allows the most immobile phase of the heart to be identified[47,48]. It also helps to improve image quality by reconstructing with very thin slices[49]. An initial scan without contrast medium is highly recommended to detect parietal calcifications and intramural haematomas. In addition, a short acquisition delay time and a contrast agent with a high iodine concentration helps in better visualization of the aorta and arterial vessels[50]. The extent of the scan depends on the physical examination of the patient. However, it is recommended to include the vessels of the neck, which are often involved in seat belt accidents, up to the pubic symphysis[51]. While extension to the lower limbs is expected in the absence of a pulse (on doppler or palpation) in cases of fractures, dislocations and penetrating trauma[38,52,53]. Indications for performing this protocol are a high-speed accident with side impact of a vehicle, sudden deceleration or a fall from great heights, which are dynamics that increase the risk of aortic injury[54]. CTA allows more accurate and precise detection of traumatic blunt injury of the thoracic aorta (TAI), intramural hematomas, contrast extravasation and pseudoaneurysms, which often occur in trauma, as well as periaortic bleeding or mediastinal hemorrhage, which may be indirectly indicative of thoracic aortic injury[55]. CTA has a high sensitivity in detecting dissection of arterial vessels, allowing rapid assessment of false lumen patency and detection of involvement or non-involvement of vessel branches (Figure 5).

CT-Urography

The urographic phase requires an additional time of several minutes, which is not always allowed in the polytrauma setting, so it should only be performed in very selected cases of suspected urinary tract injuries. The delayed acquisition time is recommended to be at least 3-5 minutes after contrast medium injection and can also be repeated if more time is needed to stain the excretory tract, we are interested in[37,56]. The urographic phase is recommended in the case of a penetrating injury of the abdomen or pel-

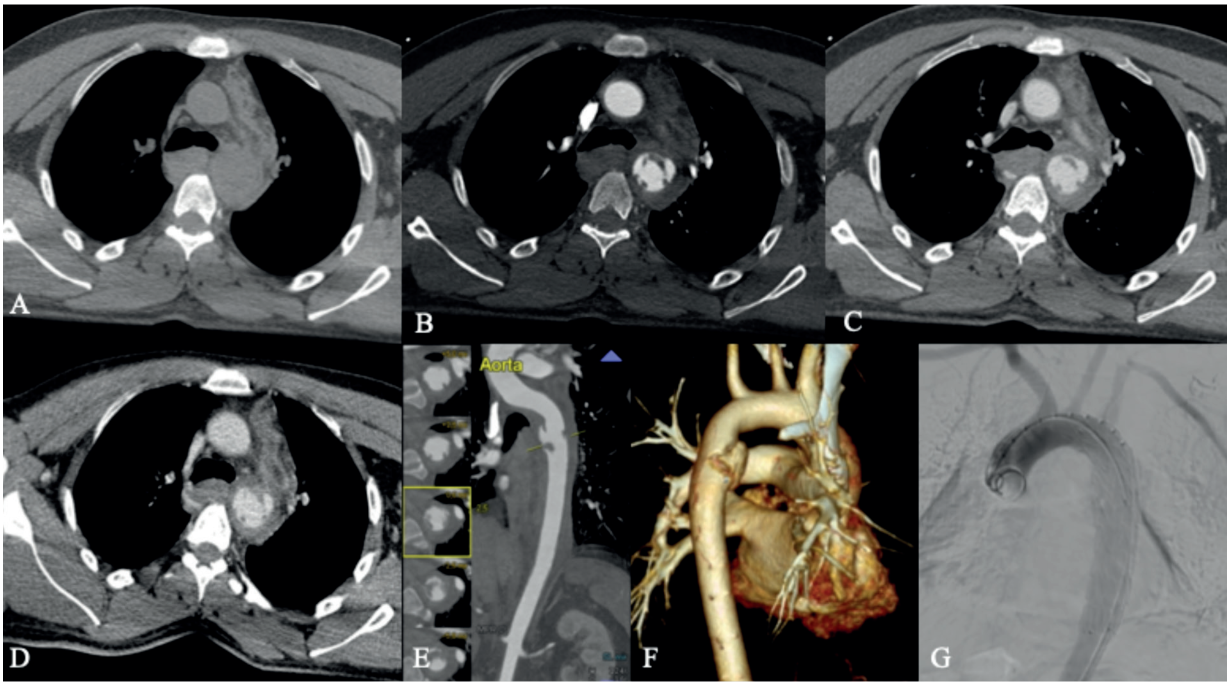

Figure 5. Traumatic aortic pseudoaneurysm in a clinically unstable 40-year-old man. (**A**) Absence of hyperattenuating material on non-enhanced scan. **B**, Angiographic CT phase shows irregularities along the inferior surface of the aortic isthmus. **C**, **D**, Venous phase and delayed phase exclude contrast pooling. **E**, MPR curve and **F**, VRT demonstrate a smooth-walled pouch adjacent to the aorta and are useful for surgical planning. **G**, Angiographic scan during endovascular surgery.

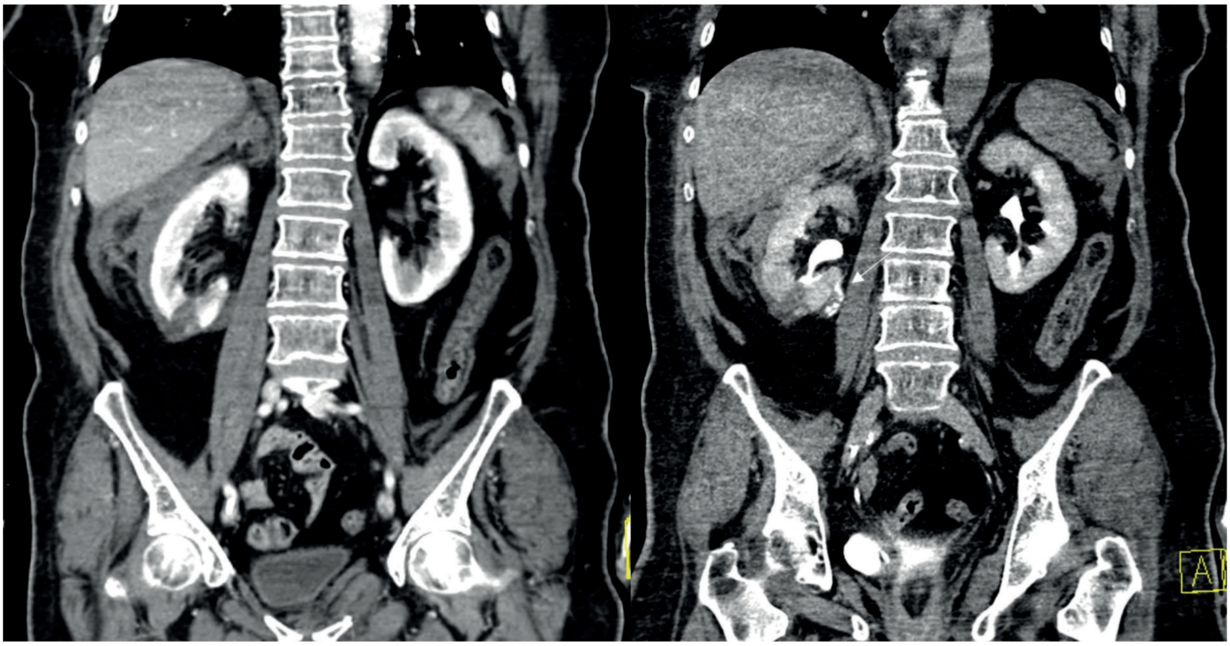

Figure 6. Renal trauma in a 55-year-old woman after road accident, coronal venous and urographic phase. The venous phase (right side) shows a laceration in the lower third of the kidney, in the urographic phase (left-side) contrast medium is visible in the renal perinephric space (white arrows), indicative of injury to the urinary tract.

vis, regardless of whether there is hematuria or not[56]. In the case of blunt trauma, however, it is recommended if macrohaematuria is present and in deceleration dynamics with severe injury to the abdomen and pelvis[57]. In suspected bladder trauma, such as pelvic fracture with haematuria or penetrating pelvic trauma, it may be useful to fill the bladder retrogradely with 300 - 350 ml of 5% diluted contrast medium and clamp the bladder catheter (CT cystogram)[58]. This allows to distinguish if the fluid in the abdomen is urine (Figure 6).

Non-Enhanced Scan

Whichever protocol is chosen, a non-enhanced scan of the head before the enhanced scans is always included[59]. While there is no agreement on unenhanced thoraco-abdominal scanning. Supporters of this protocol suggest the usefulness of these scans in facilitating the differential diagnosis of some findings that would otherwise be more difficult[60]. Non-enhanced scanning of the chest and abdomen allows rapid detection of the presence of blood, such as in parenchymal and intramural vascular haematomas[61] (Figure 7). It shows calcifications very clearly, which may be mistaken for active bleeding sites on enhanced scans[8]. The addition of non-enhanced acquisitions to the contrast medium protocol can help in the evaluation of intravascular and surgical prostheses[62,63]. The disadvantage is always the additional time to perform it and the increase in radiation dose. The dual-energy technology of new CTs could solve this by generating virtual non-enhanced images from the enhanced scans.

Dual-Energy CT Scan

To date Dual-Energy-CT (DECT) has an open recommendation, meaning “may be considered”, in the assets of polytrauma patients according to

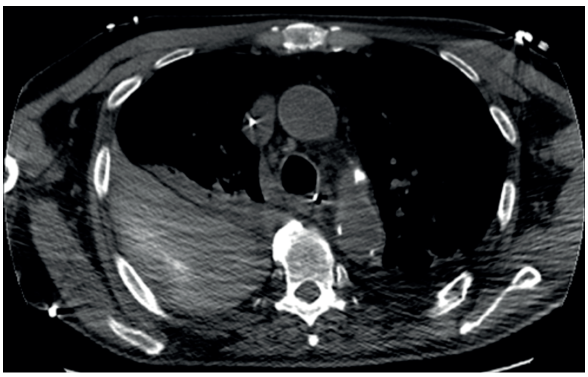

Figure 7. Non enhanced axial CT scan in a polytrauma patient with anemia showing a hematic extra-pleural effusion. Fresh blood is best depicted in unenhanced scans, visible as hyperdense material.

ESER guideline[5]. To overcome the limitations of scanning time and radiation exposure related to multi-detector computed tomography (MDCT), a number of studies have tested DECT[64]. Currently there are two clinically available DECT scanners: the dual-source computed tomography (DSCT) scanner and the single-source CT (SSCT) scanners or fast kilovoltage-switching methods[65,66]. Nicolau et al[67] observed possible advantages of DSCT scanner installation in the emergency department. DSCT scanning time was 2 minutes lower than the full imaging evaluation and radiation exposure was reduced thanks to the possibility of obtaining virtual unenhanced images[67]. Moreover, decreased temporal resolution resulted in reduced cardiac pulsations motion artifact, thus improving image interpretation[67]. Sedlic et al[68] tested scan time, and effective radiation dose of a Rapid Imaging Protocol in Trauma (RIPT), performed on a DSCT, in the setting of polytrauma. The protocol consisted of a non-contrast head CT, a CTA from vertex to pelvis and a venous scan from abdomen to pelvis. Compared to a full protocol, RIPT scored 53.7% reduction in time spent in the emergency department, 25% decreased scanning time and the mean effective radiation dose was 24.5% lower (24.66 mSv *vs.* 32.67 mSv)[68]. Another advantage of DECT imaging is the identification of traumatic marrow edema associated with non-displaced and minimally displaced fractures through the so-called virtual non-calcium images[69-79].

Recently a meta-analysis performed by Suh et al[72] on the diagnostic accuracy of DECT in bone marrow edema (BME) has showed a sensitivity of 85% and a specificity of 97%, thus indicating that DECT is useful both for confirming and excluding diagnosis of occult fractures in the spine and appendicular skeleton.

Structured Reporting

In the emergency setting, an effective communication of imaging data to referring physicians is crucial for patient care[80]. Despite all the technical developments on the image acquisition side[81-87], the radiologist's final product and most important part in his communication with clinical partners, the radiology report, has not evolved that much. Just like most other parts of a patient's medical record, it remains poorly structured text, the quality of which heavily depends on the radiologist and his experience with a particular matter. In fact, radiology reports are traditionally created as non- structured free text (FRT) presentations in narrative language. However, inconsistencies regarding content, style, and presentation can hamper information transfer and diminish the clarity of the reports, which can in turn adversely affect the extraction of the required key information by the referring physician[80]. At worst, the resulting communication errors can lead to incorrect diagnosis, delayed initiation of adequate treatment, or adverse patient outcomes[80]. Therefore, FRT should be organized and shifted toward structured reports (SR)[88-95].

A large part of the benefits of structured reporting can be attributed to the fact that most structured radiology reports are composed using a dedicated report template. When using such report templates, the radiologist reviewing the imaging study is provided with a list of predefined items relevant to the case at hand ensuring that no important information is missed. This should not only guarantee a consistently high quality of the final report, but also aid in the managing of patients[88-95].

Various radiological societies have published recommendations on reporting and promoted structured reporting as the future of reporting. The Italian Society of Medical and Interventional Radiology (SIRM) created an Italian warehouse of SR templates that can be freely accessed by all SIRM members, with the purpose of its routine use in a clinical setting[96].

Using a checklist and a systematic search pattern may help to prevent such diagnostic errors. Both radiologists and referring clinicians are keen to reduce the rate of diagnostic errors, which for radiologists accounts for as much as 4% of reports[97-101]. A retrospective review of 3,000 MRI examinations helped identify clinically significant extraspinal findings in 28.5% of patients which were not included in the original unstructured report[102]. The use of a checklist-style structured report template has been shown to improve the rate of diagnosis of non–fracture related findings on cervical CT[103].

Conclusions

When faced with polytrauma patients, a protocol does not fit everyone; the trauma team should choose the most suitable and optimized protocol, in terms of time-saving and radiation exposure, taking into account the clinical state of the patient, number and region of injuries and accident mechanism.

In the emergency setting, effective communication of imaging data to referring physicians is crucial for patient care. This communication should be based on SR.

Conflict of Interest
The Authors declare that they have no conflict of interests.

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