CURRENT OPINION

Whole-body computed tomography in severely injured patients

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Purpose of review
To provide an update on the relevant and recent studies on whole-body computed tomography (WBCT) imaging of severely injured patients.

Recent findings
The advantages of WBCT in time saving, diagnostic accuracy and even in survival have been proven in numerous studies. WBCT can also be beneficial in haemodynamically unstable major trauma patients. The CT scanner should be located close to the emergency department or even in the trauma room. The issue of radiation is still quite important, however, iterative as well as split-bolus protocols can nowadays reduce radiation significantly. The question: which trauma patient should receive WBCT and which not is not yet solved sufficiently. Postmortem WBCT has a promising potential to promptly define the definitive cause of death of trauma victims comparably to traditional autopsy.

Summary
On account of the recent advances, whole-body CT has become a crucial part of the initial in-hospital assessment of severely injured patients. It is recommended as the standard radiological tool for the emergency diagnostic work-up in major trauma patients.

Keywords
computed tomography, emergency room, major trauma, polytrauma, resuscitation, whole-body computed tomography

INTRODUCTION

Trauma is one of today's most relevant health issues. A total of 177 154 deaths in the US were classified as injury-related according to the National Vital Statistics Reports of the CDC 2011. With a rate of 184.4 deaths per 100000 population, accidents (unintentional injuries) were the leading cause of death up to the age of 54.

In addition to preclinical therapy and transportation, operative and intensive care unit treatment, early in-hospital trauma management is crucial for the survival of major trauma patients. Therefore, an early, quick, accurate and rational diagnostic workup is necessary. Whole-body computed tomography (WBCT) is increasingly becoming part of such a workup. Historically Löw *et al.* [1] from the City of Mainz, Germany was the first to report on the successful use of whole-body spiral CT in 27 major trauma patients.

WBCT is mostly defined as unenhanced CT of the head followed by contrast-enhanced CT of the chest, abdomen, and pelvis, including the complete spine. It can be conducted as single-pass or segmented WBCT.

Multiple studies have been performed to evaluate potential benefit or harm of WBCT during early resuscitation phase of multiply injured patients. The following review will focus on the relevant and current developments and controversies in this field.

TIME ASPECTS

Priority-orientated and early targeted therapy is crucial for early management of the critically injured

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KEY POINTS

- Whole-body CT has become a crucial part of the initial in-hospital assessment of severely injured patients and is nowadays the standard diagnostic tool.
- WBCT's advantages in time saving, diagnostic accuracy and even in survival have been proven in numerous studies.
- WBCT can also be beneficial in haemodynamically unstable major trauma patients, thus the CT scanner should be located close to the emergency department or even in the trauma room.
- The issue of radiation is still quite important, however, iterative as well as split-bolus protocols can nowadays reduce radiation significantly.
- The question which trauma patient should receive WBCT and which not is not yet solved sufficiently.

patient. In 1976, Cowley has introduced the concept of the 'golden hour of shock'. Thus, to a high proportion trauma management is time management. In Germany, the time from hospital admission to the beginning of WBCT is about 25 min ($N = 16\,719$) [2]. Current measurements by Gordic *et al.* showed that the completion of the trauma-related imaging work-up with WBCT can be achieved within 12 min (!) compared with 75 min in the non-WBCT control group [3▪]. Ptak *et al.* [4] reported the pure scanning time to be about 3 min. They introduced the term 'three minute multiple trauma scan'. In 2004, Kanz *et al.* [5] analyzed 125 polytrauma patients and found 6-min acquisition time for contrast-enhanced WBCT including the pilot scan. The pure scanning time was just 59 s. Current protocols may even be faster.

Furthermore, the time spent in the emergency room until arrival in the operation theatre or the intensive care unit could significantly be reduced by 30 min compared with non-WBCT trauma algorithms [6,7]. In 2010, Kanz *et al.* [8] introduced the term '*focussed assessment with computed tomography in trauma (FACTT)*' in analogy to the well known 'focussed assessment with sonography in trauma (FAST)'. This illustrates the usefulness of this kind of comprehensive and fast diagnostic tool to detect the complete pattern of injuries as early as possible.

DIAGNOSTIC ACCURACY OF WHOLE-BODY COMPUTED TOMOGRAPHY

Brown *et al.* [9], Lee *et al.* [10] and Sampson *et al.* [11] in general, demonstrated a high level of diagnostic accuracy of WBCT. Deunk *et al.* [12] and Salim *et al.* [13] observed that in 19–40% of the cases, a relevant change of the treatment based on the findings of WBCT was performed. In 2004, Kanz *et al.* [5] demonstrated that the principles of the Advanced Trauma Life Support (ATLS) concept are compatible to WBCT. For the first time, Stengel *et al.* recorded in a series of nearly 1000 polytrauma patients, exact data regarding sensitivity and specificity. An overall sensitivity of at least 80% and an overall specificity of at least 97% prove a high diagnostic accuracy of WBCT, however, there may be still uncertainties about abdominal injuries [14].

Several authors found a relevant rate of incidental nontraumatic findings in patients undergoing WBCT during the initial emergency room phase. The rate of high clinical relevance of these findings ranges from 5.6 to 8.4% [15,16▪,17].

In 588 patients with suspected major trauma, Shannon *et al.* found that there is a poor correlation between clinically suspected injuries and that found in WBCT. Over the different body regions (head, neck, chest and abdomen/pelvis) they recorded a range of 3–15% of relevant injuries that have not been suspected clinically before WBCT [18▪].

Crönlein *et al.* did an interesting and innovative study to evaluate potential benefits of a new diagnostic software prototype (Trauma Viewer) automatically reformatting CT data on diagnostic speed and quality, compared with CT-image data evaluation using a conventional CT console. They demonstrated that, after further development, the Trauma Viewer might serve as a new diagnostic feature during trauma room management. It has a high potential to improve time and quality of CT-based diagnoses and might help to accelerate decision-making regarding treatment of severely injured patients [19▪].

BENEFICIAL EFFECT OF WHOLE-BODY COMPUTED TOMOGRAPHY ON MORTALITY

In 2009, the group around Huber-Wagner *et al.* [20] were the first to prove a positive effect of WBCT on survival in a large retrospective registry analysis. Consecutively, several retrospective studies were able to confirm this positive effect on survival [2,21–23]. In 2016, the group around Sierink *et al.* [24▪▪] published an ambitious randomized controlled trial to assess the effect of WBCT scanning compared with a standard work-up on mortality in patients with trauma. They included about 540 patients in each diagnostic arm. They found that the overall in-hospital mortality did not differ between the two groups. In the subgroup of polytrauma patients they found a nonstatistically significant difference in mortality of 3% (22 versus 25% in favour of initial WBCT). The authors have performed a great protocol and study; however, whenever going into the methodology in-depth, some criticism is justified [25▪]. The authors estimated their target sample size assuming a reduction of in-hospital mortality of 5% instead of 3% which is the true value according to the literature. This results in a lower and thus underestimated sample size resulting in almost nonsignificant findings based on questionable assumptions. The authors also report that 46% of the patients in the standard work-up group underwent a total-body CT scan because of overlapping effects of sequential segmental CT scans. This means that 73% rather than 50% of all patients received WBCT scans. Thus, experts think that no clear conclusions can be drawn from this study, except that doctors regard WBCT scanning as a substantial and integral part of major trauma management [25▪].

Currently, several well done meta-analyses have been published. All of them found a significant positive effect on survival in the WBCT group. The pooled odds ratios for survival ranged between 0.66 and 0.79. The included numbers of patients in these meta-analyses ranged from 14 000 to nearly 35 000. This means that the chance to survive is increased by at least 21% up to 34% for those patients undergoing WBCT during the initial trauma management compared with those undergoing conventional radiological work-up. Each of these authors concluded that WBCT is associated with better outcomes [7,26,27▪,28,29]. Figure 1 shows the trauma room algorithm of the Department of

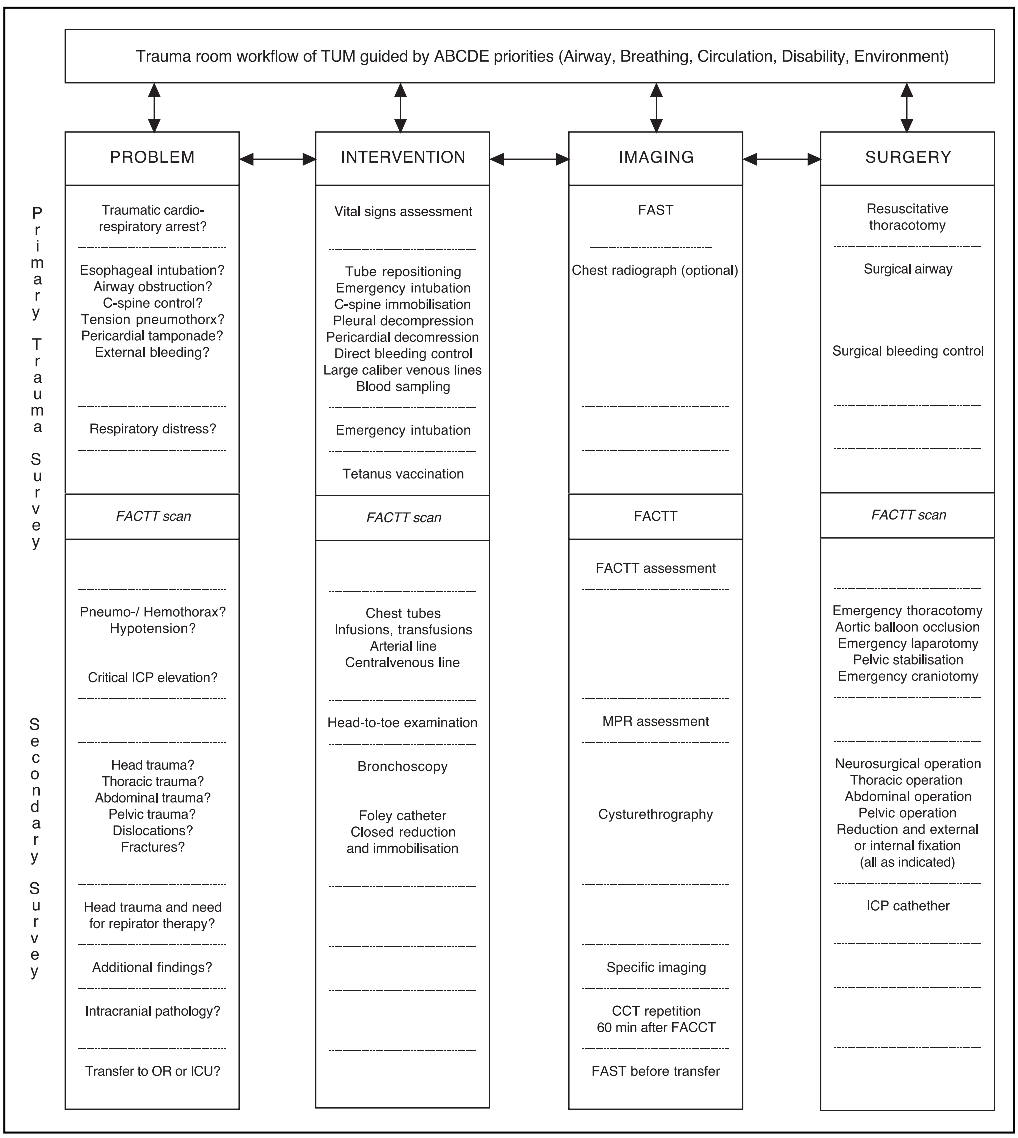

FIGURE 1. Whole-body CT (WBCT) or Focussed Assessment with Computed Tomography in Trauma (FACTT)-based trauma room algorithm of the Department of Trauma Surgery, Klinikum rechts der Isar, Technical University Munich (TUM), Germany. WBCT is intended to be performed within the first 15 min after admission.

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BENEFICIAL EFFECT OF WHOLE-BODY COMPUTED TOMOGRAPHY ON MORTALITY IN UNSTABLE PATIENTS

For a long time, a common and dogmatic opinion was that WBCT must not be performed in major trauma patients in shock. The potential disadvantages for unstable patients are that it could be difficult to escalate care in many CT scanner rooms wherever access to the patient is poor, lighting is bad, resuscitation equipment is less available, and it may require transporting patients to other parts of the hospital. Some warned about CT as a 'tunnel-to-death'. However, there are currently three studies that approached this topic in a nondogmatic way. They all demonstrated that even in haemodynamically unstable major trauma patients, WBCT during trauma resuscitation significantly increased survival. Huber-Wagner *et al.* showed that the mortality rate of patients in severe shock (<90 mmHg blood pressure at hospital admission) in the WBCT group was 42.1% compared with 54.9% in the non-WBCT group ($N = 16\,719$ patients). The number needed to treat (NNT) in this subgroup was 20. They conclude that the application of WBCT in haemodynamically unstable severely injured patients is well tolerated, feasible and justified if performed quickly within a well structured environment and by a well organized trauma team [30]. Tsutsumi *et al.* [31▪] confirmed these findings in their analysis of the Japan Trauma Data Bank ($N = 5809$ patients). The same results were reported by Wada *et al.* On the basis of an analysis of 152 patients, they found that WBCT performed before emergency bleeding control might be associated with improved survival, especially, in patients with a high risk of death [32]. Figure 2 shows a haemodynamically unstable major trauma patient undergoing WBCT in the trauma room of the Department of Trauma Surgery of the Technical University of Munich, Germany.

EFFECT OF THE LOCATION OF THE CT-SCANNER

As whole-body computed tomography increasingly became the standard diagnostic technique during the resuscitation of severely injured patients, consistently the question arose where the CT scanner ideally should be located. Huber-Wagner *et al.* addressed this question and based on an analysis of 8004 patients of the TraumaRegistry of the German Trauma Society (DGU) found the following for the first time. A close distance of the CT scanner to the trauma room has a significant positive effect on the probability of survival of severely injured patients. The closer the CT is located to the trauma room, the better the probability of survival. Distances of more than 50 m had a significant negative effect on the outcome. If new emergency departments are planned or rebuilt, the CT scanner should be placed less than 50 m away from or preferably in the trauma room [33].

REDUCTION OF RADIATION

The issue of radiation is crucial whenever discussing the advantages and disadvantages of WBCT. The

FIGURE 2. Management of a severely injured patient in the trauma room of the Department of Trauma Surgery, Klinikum rechts der Isar, Technical University Munich, Germany.

number of CT examinations increases every year so that CT imaging is made responsible for the increase of radiation exposure, which potentially increases the risk of developing cancer [34,35].

New software algorithms seem to have a great potential for dose reduction. Iterative reconstruction is a better and more accurate way to produce a CT image from the raw data compared with the normal filtered back projection. However, it takes slightly more time to calculate images with iterative techniques. As computer technology improves, it is nowadays possible to use these new reconstruction methods within a normal time setting. With these iterative reconstruction techniques, it is possible to reduce artefacts and noise in CT images. A reduction of 30–80% with iterative reconstruction techniques keeps the same image quality compared with a normal dose setting and filtered back projection images. Thus, the effective dose of WBCT should no longer be estimated to be around the well known 10–25 mSv, but rather 5–10 mSv, as iterative techniques are becoming more widespread [36–38]. Thus, the risk of radiation-related long-term complications is reduced and is outweighed by the positive effects of WBCT.

CONTRAST ENHANCEMENT BY SPLIT-BOLUS TECHNIQUE

For the evaluation of multitrauma patients, a variety of whole-body computed tomography scanning protocols exist. Frequently, multiple pass protocols with a repeated radiation exposure are used. New split-bolus contrast protocols can reduce the number of passes through the body, and thereby, radiation exposure. The first bolus of contrast agent will appear as the venous phase and the delayed second bolus – shortly before the single pass WBCT-scan – will appear as the arterial phase. Beenen *et al.* [39▪] and Hakim *et al.* [40▪] have performed well done studies to evaluate such dual-phase protocols. They both found that the image quality was excellent, that acquisition time could be reduced and that radiation was less. To our opinion, there is a great potential within these techniques for the further optimization of WBCT protocols in the future.

COST-EFFECTIVNESS OF WHOLE-BODY COMPUTED TOMOGRAPHY

Lee *et al.* recently showed that WBCT is significantly more cost-effective compared with selective organ CT scanning. In his model, he calculated about 15 000 US$ for WBCT compared with 17 000 US$ for selective organ CTs. In his cost–utility analysis, he found WBCT to be a cost-effective use of resources [41]. Nearly the same results were found by van Vugt *et al.* [42].

POSITIONING OF THE ARMS

Loewenhardt *et al.* currently demonstrated that the effective dose was 16–22% lower, in a series of 100 polytrauma patients whenever the arms were raised. With the latest design of a 64-slice multi detector CT, the effective dose could be reduced even to 10.8 mSv, compared 14.3 mSv with a 14-slice multi detector CT (both arms raised; $P < 0.001$) [43]. In our opinion, haemodynamically stable trauma patients should be scanned with arms up and haemodynamically unstable patients with arms positioned alongside the abdomen in order to save time.

INDICATIONS FOR OR AGAINST WHOLE-BODY COMPUTED TOMOGRAPHY

WBCT has become a routine practice in the initial in-hospital assessment of polytrauma patients. Whilst this is associated with increased survival, there are also negative CT-scans. As no defined selection criteria exist, indications for or against WBCT vary widely. Treskes *et al.* [44] in their review on indications for WBCT in trauma, concluded that clear indications are lacking. Davies *et al.* aimed to develop a scoring system that improves patient selection for WBCT. On the basis of the analysis of 255 patients, they developed the following decision tool. Unconsciousness or signs of spinal cord injury trigger WBCT. The more regions are injured, the more haemodynamically unstable the patients are, the worse the respiratory function is and the lower the Glasgow coma scale is the more WBCT is indicated. The more serious the trauma mechanism is (fall greater than 5 m, accident with pedestrian, road traffic accident) the more WBCT is indicated [45▪].

In 2015, Huber-Wagner *et al.* presented a conference paper introducing the WBCT score based on 78 180 patients (Huber-Wagner 2015, Berlin, abstract accessible at: doi: 10.3205/15dkou173). They present a score from -16 to +35 points. Negative values represent no estimated usefulness of WBCT. Values from 0 to 3 represent that it is unclear whether WBCT will be beneficial. Values from 4 to 16 and values from 17 to 35 represent moderate or high expected benefit from WBCT, respectively. The WBCT score consists of 12 different parameters including anatomical, physiological and trauma mechanism-related issues.

POSTMORTEM WHOLE-BODY COMPUTED TOMOGRAPHY

If a patient dies in the emergency room, death has to be testified. The attending physician team has also the duty to search for and to find out the cause of death. One method to do so can be prompt postmortem computed tomography (pmCT). This method is an adjunct to assist in postmortem investigations since 1983. Since 1994, it is also seen as an alternative to invasive autopsy. Especially in trauma victims, pmCT is becoming more and more common. It can take weeks up to months to receive the final results from invasive autopsy. This can be quite incriminatory for the surviving dependants as well as for the treating trauma team. Sifaoui *et al.* [46] demonstrated that sensitivity and specificity of pmCT to detect posttraumatic chest injuries is quite high compared with the gold standard of classic autopsy. Schmitt-Sody *et al.* [47▪] found out that pmCT was in good accordance with autopsy in 94.1% of the cases to reveal the cause of death. Roberts *et al.* assessed 182 unselected cases to investigate the cause of death of pmCT, pmMRT and invasive autopsy. They found that compared with traditional autopsy, CT was a more accurate imaging technique than MRI for providing a cause of death. However, the major discrepancy rate between autopsy and pmCT was 32% [48]. In 2017, Rutty *et al.* [49▪] investigated the diagnostic accuracy of pmCT with targeted coronary angiography versus traditional autopsy in 241 mostly nontraumatic cases. They found that pmCT angiography could be used to avoid invasive autopsy. Overall, these results demonstrate that the technique of pmCT has great potential for the future to promptly define the definitive cause of death of trauma victims comparably to traditional autopsy.

CONCLUSION

WBCT has become a crucial part of the initial in-hospital assessment of severely injured patients. Its advantages in time saving, diagnostic accuracy and even in survival have been proven in numerous studies. It can also be beneficial in haemodynamically unstable major trauma patients. The CT scanner should be located close to the emergency department or even in the trauma room. The issue of radiation is still quite important, however, iterative as well as split-bolus protocols can nowadays reduce radiation significantly. Even cost–utility analyses are beneficial for whole-body CT. The question: which patient should receive WBCT and which not is not yet solved sufficiently. Postmortem WBCT has a promising potential to promptly define the definitive cause of death of trauma comparably to traditional autopsy.

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Conflicts of interest

There are no conflicts of interest

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