Introduction of a treatment algorithm can improve the early management of emergency patients in the resuscitation room

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Summary
Introduction: Successful management of emergency patients with multiple trauma in the hospital resuscitation room depends on the immediate diagnosis and rapid treatment of the most life-threatening injuries. In order to reduce the time spent in the resuscitation room, an in-hospital algorithm was developed in an interdisciplinary team approach with respect to local structures. The aim of the study was to analyse whether this algorithm affects the interval between hospital admission and the completion of diagnostic procedures and the start of life-saving interventions. Moreover, in-hospital mortality was investigated before and after the algorithm was introduced.

Material and methods: In this prospective study, all consecutive trauma patients in the resuscitation room were investigated before (group I, 01/04—10/04) and after (group II, 01/05—11/05) introduction of the algorithm. The times between hospital admission and the end of the diagnostic procedures (ultrasound [sono], chest X-ray [CF], and cranial computed tomography [CCT]), and between hospital admission and the start of life-saving interventions were registered and in-hospital mortality analysed.

KEYWORDS
Algorithm;
Resuscitation room;
Emergency department;
Emergency patients;
Time consumption

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Results: In the study period, 170 patients in group I and 199 patients in group II were investigated. Injury severity score (ISS) were comparable between the two groups. The intervals between admission and completion of diagnostic procedures were significantly lower after the algorithm was introduced (mean ± S.D.): sono (11 ± 10 min versus 7 ± 6 min, p < 0.05), CF (21 ± 12 min versus 12 ± 9 min, p < 0.01), and CCT (55 ± 27 min versus 32 ± 14 min, p < 0.01). Moreover, the interval to the start of life-saving interventions was significantly shorter (126 ± 90 min versus 51 ± 20 min, p < 0.01). After introducing the algorithm, in-hospital mortality was reduced significantly from 33.3% to 16.7% (p < 0.05) in the most severely injured patients (ISS ≥ 25).

Conclusion: The introduction of an algorithm for early management of emergency patients significantly reduced the time spent in the resuscitation room. The periods to completion of sono, CF, and CCT, respectively, and the start of life-saving interventions were significantly shorter after introduction of the algorithm. Moreover, introduction of the algorithm reduced mortality in the most severely injured patients. Although further investigations are needed to evaluate the effects of the Heidelberg treatment algorithm in terms of outcome and mortality, the time reduction in the resuscitation room seems to be beneficial.

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Introduction

Severe trauma is becoming the most frequent cause of premature death in industrialised countries. Up to 8 million patients suffer from trauma in Germany annually, and in the year 2000 about 20,000 patients subsequently died of their injuries. Although the exact number of patients is still unknown, by extrapolating from the annual incidence of injured patients, it has been estimated that up to 40,000 patients suffer from severe trauma in Germany every year.

Compared with admission to a level II or III hospital, primary admission to a level I hospital improves the outcome and reduces the in-hospital mortality in the most severely injured patients. Therefore, it is recommended that severely injured patients are admitted routinely to the emergency department (ED) of a level I hospital.

After admission, successful in-hospital management depends on immediate diagnosis and rapid treatment of life-threatening injuries by an interdisciplinary team, including general surgeons, trauma specialists, anaesthesiologists, and radiologists. Studies have reported 14–33% of potentially preventable deaths in the early in-hospital management of severely injured patients. A retrospective review of the San Diego trauma registry with 22,577 trauma patients showed errors affecting the outcome in 4%. In particular, failure to evaluate the abdomen appropriately was found in 22%. In up to 13% the relevant findings were not recognised until more than 24 h after admission, which resulted in a delay in diagnosis. In up to 11% there was an unacceptable time delay to the start of emergency interventions.

The authors stated that 6% of all trauma patient deaths were rated as preventable or potentially preventable, and more than half of all errors had occurred in the resuscitation phase. After admission, the interval to completion of diagnostic procedures and to the start of life-saving interventions should be as short as possible since time to intervention affects patient survival and prolonged times are associated with negative outcome.

As a consequence of these results, treatment algorithms have been developed as an instrument for internal quality management and assurance in order to reduce the time spent in the ED, to optimise the management of emergency patients early in the in-hospital course, and to reduce morbidity and mortality. As a result of these efforts, comprehensive algorithms for specific injuries have been shown to optimise management. However, when creating algorithms, differences between national and international standards concerning logistics and diagnostic features should be considered.

Hospital algorithms aim to improve the quality of care early in the course of in-hospital treatment by leading to a more rapid diagnosis and subsequent treatment.

The aim of the present study was to investigate whether the intervals between admission and both completion of diagnostic procedures and the start of life-saving interventions (e.g., laparotomy, decompression of the brain) can be reduced and, furthermore, if mortality can be improved by employing an in-hospital treatment algorithm adapted to the local situation.
Material and methods

The resuscitation room

The resuscitation room of the surgical ED is designed for the critical care of severely injured patients—24 h per day, 365 days per year. At our institution the resuscitation room is located on the ground floor next to the arrival area for ambulances and helicopters.

The resuscitation room has two emergency units, and two patients can be managed simultaneously. All the equipment needed for emergency diagnostic and emergency therapy for contemporary advanced trauma life support is available. An ultrasound device and a mobile X-ray system is available in the resuscitation room.

The multislice computed tomography (MSCT) is located on the first floor just above the resuscitation room; therefore, one of two available elevators must be used to transfer patients. A period of up to 5–10 min is required for transfer. A comparable additional amount of time is needed to transfer the patient from the MSCT to one of the 13 operating rooms on the second floor. After finishing the resuscitative phase with or without an emergency operation, patients are transferred to the ICU on the second floor just beside the operating room.

Development of an interdisciplinary algorithm

In order to reduce the time spent on the early management of emergency trauma patients who are admitted to the resuscitation room of the ED, a treatment algorithm was developed with interdisciplinary collaboration between the Department of Anaesthesiology, the Department of Surgery and the Division of Trauma and Plastic Surgery of the Department of Surgery, and the Department of Radiology with respect to the local structure of our level I hospital (Figure 1). After the initial concept for early trauma management was developed by the Department of Anesthesiology in November 2001, it was presented to an interdisciplinary conference to all related departments in December 2001. After revision the second version of the concept was presented to all collaborators in June 2002. Two more interdisciplinary conferences with all participating institutions were held in October 2003 and August 2004 to discuss all aspects and interests raised by the three departments, to reach agreement, and finally to complete the Heidelberg treatment algorithm. The requests of all collaborators were factored in, and compromises were reached. Simultaneously, data were collected from 01/04 to 10/04 in order to build up a reference group before introducing the Heidelberg treatment algorithm. In November 2004 the Heidelberg treatment algorithm was introduced as a compulsory measure for trauma management in the resuscitation room of the surgical ED of the University of Heidelberg. Subsequently a second study period between January 2005 and November 2005 was used to evaluate implementation of the algorithm.

The Heidelberg treatment algorithm

After being informed by the medical call center, the “basic team” members (Table 1) and an independent investigator for data collection who is not involved in patient care are paged individually by a nurse working in the admission area. The staff anesthesiologist and the staff surgeon act as team leaders of the basic team and are responsible for the entire management from hospital admission until the patient is transferred to the ICU. Moreover, if the basic team leader considers it to be necessary, additional specialists from other departments are also called (e.g., neurosurgeon, vascular surgeon).

Early trauma management represents an area of joint effort for surgeons, anesthesiologists, and radiologists, and therefore these three groups must work together systematically in order to achieve the best outcome for trauma patients. The Heidelberg treatment algorithm pools these three core competencies (anesthesiology, radiology, and surgery) in a systematic way and the patients are treated for their haemodynamic and respiratory

| Table 1 Basic team members in the resuscitation room of the Department of Surgery |
|-------------------------------|---------------------------------|-----------------|
| Department        | Physicians                                           | Nurse staff          |
| Surgery           | Two surgeons (one intern and one specialist or assistant medical director) | Two nurses          |
| Anesthesiology    | Two anesthesiologists (one intern and one specialist or assistant medical director) | One nurse           |
| Radiology         | One radiologist (intern)                               | One medical-laboratory assistant |
condition. For this, the Heidelberg treatment algorithm, whose structure represents an adaptation of a protocol put forward by other authors, is divided into four main periods (red, yellow, blue and green, Figure 1)\(^{22,23}\):

1. **RED** period: This period is completed within the first 5 min after admission. The primary survey should be performed to control vital functions, establish hemodynamic monitoring, and manage airway control.

   - **Surgery:** bleeding control, immobilization, undress the patient
   - **Anesthesiology:** breathing sounds, check ET, intubation if necessary, blood pressure, venous access, volume replacement, emergency drugs if necessary, ABG, laboratory, crossmatch
   - **Radiology:** sonography (FAST), chest film

   Patient conditions: stable or unstable? Operation is indicated immediately?

2. **YELLOW** period: This period aims at stabilizing vital functions and emergency diagnostic procedures.

   - **Surgery:** whole body check
   - **Anesthesiology:** fluid therapy, stomach tube, antibiotics, if indicated, catheter in an artery, if indicated, control of ABG
   - **Radiology:** multislice computer-tomography of the head and the trunk

   Patient conditions: stable or unstable? Operation is indicated immediately?

3. **BLUE** period: This period focuses on further diagnosis and stabilization.

   - **Surgery:** urinary catheter, tetanus prophylaxis, emergency consults, reevaluation
   - **Anesthesiology:** fluid therapy, packed blood cells, fresh frozen plasma, emergency drugs, thermocontrol, reevaluation
   - **Radiology:** control of chest film, radiological examination of spine and extremities, if indicated

   Patient conditions: stable or unstable? Operation is indicated immediately?

4. **GREEN** period: This period is dedicated to complementary diagnosis, final interventions, and operations.

   - **Surgery:** organization: OP, documentation
   - **Anesthesiology:** central venous line if needed, transesophageal echocardiography, if needed, bronchoscopy, if needed, fluid control, organization: ICU, documentation
   - **Radiology:** CT-diagnosis, control of sonography, documentation

   → documentation contemporary and decide

   “Caution: critical result”

   Patient conditions: stable or unstable? Operation is indicated immediately?

Figure 1 Heidelberg treatment algorithm for emergency patients admitted to the resuscitation room of surgical emergency department.
Table 2 In the following circumstances major trauma has to be assumed (modification of Ref.7):

- Fall from heights (>3 m)
- Ejection from motor vehicle
- Death of a co-driver
- Pedestrian or biker were hit
- Motor cycle or motor vehicle accident at high speed
- Enforced deformity of vehicle
- Entrapment
- Spilling
- Patients suffering from explosion injury

is implemented. In addition, the abdomen, the pleura, and the pericardium, respectively, are examined by ultrasound, and chest X-rays are taken.24,25 Moreover, peripheral bleeding is stopped by compression, and the patient is immobilised.

(2) In the YELLOW period (6—15 min after admission) additional life-saving interventions are performed, if indicated (e.g., thoracic drainage in tension pneumothorax). The patient receives a whole-body multislice computed tomography in the following circumstances:
- immediate life-saving surgical interventions are not indicated (e.g., laparotomy),
- the haemodynamic and respiratory condition is stable,
- the patient has been intubated and mechanically ventilated and/or has a history or signs of multiple injuries (Table 2).

(3) In the BLUE period (16—30 min after admission) further haemodynamic stabilisation is carried out, a urinary catheter is placed, and the patient receives a tetanus vaccination if indicated. The patient is reevaluated, and, if necessary, additional investigations are initiated. In this period, the chest X-ray and plain films of the spine or the extremities are taken, if indicated.

(4) In the GREEN period (31—60 min after admission), any outstanding diagnostic procedures can be carried out, and definitive care, and/or operations/interventions can be planned and organised. It is essential that all results are documented in this period.

During all four periods of the Heidelberg treatment algorithm, it is vital that the patient’s haemodynamic and respiratory condition is evaluated repeatedly. Furthermore, the need for an immediate operation/intervention (e.g., burr hole, laparotomy) must be reevaluated at every step in the treatment algorithm.

Figure 2 Heidelberg treatment algorithm placed in the resuscitation room for reference.

The Heidelberg treatment algorithm was introduced in November 2004, after all medical and non-medical staff members had been briefed between July and October 2004 to explain the underlying interdisciplinary concept. Moreover, instruction manuals and presentations were made available via the hospital intranet. Finally, posters illustrating the Heidelberg treatment algorithm were placed in the resuscitation room, in the CT area, in the ICU, and in the operating rooms for reference purposes (Figure 2). Small hand-outs were distributed to all co-workers. However, no practical training was given beforehand.

Data collection

The study was approved by the local ethical committee. After hospital admission, patients were investigated in the resuscitation room before (group I, 01/04—10/04) and after (group II, 01/05—11/05) the introduction of the Heidelberg treatment algorithm. Data were collected by a non-dependent investigator who was not involved in patient care by using a standardised data entry form. All consecutive trauma patients were included in the study during the respective periods and none was specifically selected or excluded. In addition to the patient characteristics, injury severity score (ISS), and Glasgow coma scale (GCS), a study nurse on call who was not involved in patient care calculated the intervals for each patient from admission to completion of ultrasound, chest X-ray, and cranial computed tomography using standardised and computer-based investigation sheets, and, if this was considered necessary, until immediate life-saving operations such as laparotomy or decompression of the brain had been carried
out. In contrast, measures to control and restore the patient’s vital functions (airway, breathing, circulation—the “ABCs”) were not defined as lifesaving interventions, but rather as basic therapy. The patients were stratified to different ISS-dependent groups (ISS ≤ 15, light injury; ISS 16–24, moderate injury; ISS ≥ 25, severe injury). Moreover, the in-hospital mortality was documented.

Data analysis

All data were entered into a database and analysed (SPSS, Version 11.5.1). The results are expressed as absolute numbers, percentage, or mean ± standard deviation (S.D.). Possible confounding variables such as age, injury severity score and Glasgow coma scale were tested in a multidimensional (multivariate) analysis of variance (varimax). After verifying normal distribution by using the Kolmogorov—Smirnov test, the two groups were further analysed with respect to intervals and mortality by using Student’s t-test and Chi-squared test, respectively. In all comparisons, a p < 0.05 (β = 0.2) was considered statistically significant.

Results

Patient characteristics

In the study period, a total of 369 patients were investigated after admission to the trauma resuscitation room of the University of Heidelberg, with 170 in group I and 199 in group II.

The patient demographics of group I and group II were comparable with respect to age (44 ± 20 years versus 42 ± 23 years), male sex (74% versus 69%), ISS (20 ± 18 points versus 19 ± 15 points), and initial GCS (11 ± 4 points versus 11 ± 6 points), respectively, and no significant differences were observed (Table 3).

The aetiology of injuries was also comparable in the two groups and showed no significant differences: the leading causes of injury were road traffic accidents (41% versus 43%), followed by falls from a significant height (29% versus 30%), suicide attempts (3% versus 3%), and acts of violence (4% versus 3%). Other causes amounted to 23% in group I and 21% in group II.

As demonstrated in Table 3, the pattern of injuries was also comparable in the two groups and no significant differences were seen: the leading injuries in group I and II were head injuries (59% versus 57%), followed by injuries of the extremities (38% versus 37%), thoracic injuries (29% versus 30%), abdominal and pelvic injuries (19% versus 17%), and spinal injuries (16% versus 14%).

Ultrasound and radiodiagnostics

As summarised in Table 3, the number of patients who were examined by ultrasound (95% versus 94%) and in whom chest X-rays were taken (91% versus 88%), respectively, was comparable in the two groups and showed no significant differences. In contrast, the overall number of patients who underwent CT was higher in group II than in group I (62% versus 46%, p < 0.01). As summarised in Table 4, after introduction of the algorithm CT examinations and emergency interventions, depended on the severity of injury, with an 85% rate of CT and

<table>
<thead>
<tr>
<th></th>
<th>Group I (n = 170)</th>
<th>Group II (n = 199)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>44 ± 20 (2–90; 44)</td>
<td>42 ± 23 (0–85; 37)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Male gender (n, %)</td>
<td>126 (74)</td>
<td>137 (69)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Injury severity score (ISS)</td>
<td>20 ± 18 (4–75; 13)</td>
<td>19 ± 15 (1–75; 14)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Head injury (n, %)</td>
<td>100 (59)</td>
<td>113 (57)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Extremity injury (n, %)</td>
<td>65 (38)</td>
<td>74 (37)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Thoracic injury (n, %)</td>
<td>49 (29)</td>
<td>60 (30)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Abdominal/pelvic injury (n, %)</td>
<td>32 (19)</td>
<td>34 (17)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Spinal injury (n, %)</td>
<td>27 (16)</td>
<td>28 (14)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Ultrasound (n, %)</td>
<td>162 (95)</td>
<td>187 (94)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Chest film (n, %)</td>
<td>154 (91)</td>
<td>175 (88)</td>
<td>n.s.</td>
</tr>
<tr>
<td>CCT (n, %)</td>
<td>78 (46)</td>
<td>123 (62)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Life-saving intervention (n, %)</td>
<td>32 (19)</td>
<td>58 (29)</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

Mean ± S.D. (min–max, median) and absolute number (and as a percentage), respectively. CCT: cranial computed tomography with multislice scanner; n.s.: not significant.
Table 4  Radiodiagnosics, life-saving interventions, and mortality with respect to the injury severity score (ISS) before (group I) and after (group II) introduction of the treatment algorithm

<table>
<thead>
<tr>
<th>ISS ≤ 15</th>
<th>Group I (n = 170)</th>
<th>Group II (n = 199)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients (n, %)</td>
<td>83 (48.6)</td>
<td>99 (49.7)</td>
<td>0.83</td>
</tr>
<tr>
<td>Ultrasound (%)</td>
<td>93</td>
<td>93</td>
<td>0.80</td>
</tr>
<tr>
<td>Chest film (%)</td>
<td>89</td>
<td>88</td>
<td>0.83</td>
</tr>
<tr>
<td>CCT (%)</td>
<td>45</td>
<td>52</td>
<td>0.34</td>
</tr>
<tr>
<td>Life-saving intervention (%)</td>
<td>11</td>
<td>17</td>
<td>0.23</td>
</tr>
<tr>
<td>Mortality (%)</td>
<td>0.0</td>
<td>0.0</td>
<td>—</td>
</tr>
<tr>
<td>ISS 16–24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patients (n, %)</td>
<td>36 (21.4)</td>
<td>34 (17.1)</td>
<td>0.30</td>
</tr>
<tr>
<td>Ultrasound (%)</td>
<td>94</td>
<td>88</td>
<td>0.38</td>
</tr>
<tr>
<td>Chest film (%)</td>
<td>89</td>
<td>88</td>
<td>0.90</td>
</tr>
<tr>
<td>CCT (%)</td>
<td>44</td>
<td>47</td>
<td>0.80</td>
</tr>
<tr>
<td>Life-saving intervention (%)</td>
<td>22</td>
<td>29</td>
<td>0.50</td>
</tr>
<tr>
<td>Mortality (%)</td>
<td>13.3</td>
<td>11.8</td>
<td>0.85</td>
</tr>
<tr>
<td>ISS ≥ 25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patients (n, %)</td>
<td>51 (30.0)</td>
<td>66 (33.2)</td>
<td>0.51</td>
</tr>
<tr>
<td>Ultrasound (%)</td>
<td>98</td>
<td>99</td>
<td>0.67</td>
</tr>
<tr>
<td>Chest film (%)</td>
<td>96</td>
<td>89</td>
<td>0.14</td>
</tr>
<tr>
<td>CCT (%)</td>
<td>51</td>
<td>85</td>
<td>0.0001</td>
</tr>
<tr>
<td>Life-saving intervention (%)</td>
<td>33</td>
<td>47</td>
<td>0.12</td>
</tr>
<tr>
<td>Mortality (%)</td>
<td>33.3</td>
<td>16.7</td>
<td>0.04</td>
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</table>

All

<table>
<thead>
<tr>
<th></th>
<th>Group I (n = 170)</th>
<th>Group II (n = 199)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients (n, %)</td>
<td>170 (100.0)</td>
<td>199 (100.0)</td>
<td>—</td>
</tr>
<tr>
<td>Ultrasound (%)</td>
<td>95</td>
<td>94</td>
<td>0.67</td>
</tr>
<tr>
<td>Chest film (%)</td>
<td>91</td>
<td>88</td>
<td>0.35</td>
</tr>
<tr>
<td>CCT (%)</td>
<td>46</td>
<td>62</td>
<td>0.002</td>
</tr>
<tr>
<td>Life-saving intervention (%)</td>
<td>19</td>
<td>29</td>
<td>0.02</td>
</tr>
<tr>
<td>Mortality (%)</td>
<td>12.9</td>
<td>7.5</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Total number of patients and as a percentage. CCT: cranial computed tomography with multislice scanner; ISS: injury severity score.

a 47\% rate of emergency interventions in patients with an ISS ≥ 25.

After introduction of the algorithm ultrasound (11 ± 10 min versus 7 ± 6 min, \( p < 0.05 \)) and chest X-rays (21 ± 12 min versus 12 ± 9 min, \( p < 0.01 \)) were completed sooner in group II than in group I. In addition, with the algorithm, the interval between the patient’s admission and termination of the CT scan was significantly shorter in group II than in group I (32 ± 14 min versus 55 ± 27 min, \( p < 0.01 \)). The intervals between admission and completion of the diagnostic procedures are shown in Figure 3.

**Life-saving interventions**

After introduction of the algorithm more patients were scheduled for immediate surgical intervention (29\% versus 19\%, \( p < 0.05 \), Table 3), and more interventions were performed (1.3 ± 0.4 versus 1.1 ± 0.3, \( p < 0.05 \)) in each of these patients. In these patients, in group II and group I immediate

![Figure 3](image-url)
decompression of the brain (34.3% versus 35.4%) and laparotomy (34.3% versus 21.4%) were the most frequently performed emergency interventions. Furthermore, as demonstrated in Figure 3, the intervals between the patient's admission and the start of these life-saving interventions were significantly reduced after the algorithm had been introduced in group II, compared with group I (51 ± 20 min versus 126 ± 90 min, p < 0.01).

Mortality

According to their ISS, the patients were divided into three categories. The numbers of patients in each category were comparable in group I and II (ISS ≤ 15, light injury, 49% versus 50%; ISS 16–24, moderate injury, 21% versus 17%, and ISS ≥ 25, severe injury 30% versus 33%) (Table 4).

Overall, the introduction of the algorithm showed a non-significant trend towards a reduction in mortality in group II, compared with group I (7.5% versus 12.9%). However, the reduction in mortality reached statistical significance in the most severely injured patients (ISS ≥ 25) and was 33.3% in group I as compared with 16.7% (p < 0.05) in group II after introduction of the algorithm.

Discussion

The present study has shown that an association between the introduction of an interdisciplinary treatment algorithm in the resuscitation room, adapted to local structures, and a reduction in the intervals between admission and completion of emergency diagnostic procedures and the start of life-saving interventions. Moreover, after introduction of the algorithm, a significant reduction in in-hospital mortality was observed in the most severely injured patients. Because of the potential for bias with this non-randomised single-centre design, however, we cannot exclude that other factors (e.g., more involvement in trauma management, better motivation of co-workers, better trauma training) may at least partially have contributed to this change in behaviour.

Because, the early management in the resuscitation room plays a crucial role in the management of patients with multiple injuries and the severely ill,26 it is now common practice to introduce formal trauma teams for trauma management in the resuscitation room, and it is well known that these concepts provide clinical benefits.27–34 In particular, studies have shown that the introduction of a full time trauma team reduces in-hospital mortality.6,28,35 Moreover, the treatment of multiple trauma and critically ill patients was postulated to be a matter of time management.22 For instance, logistic regression of 165 patients suffering from isolated abdominal trauma has shown that the probability of death increased approximately 1% for each 3 min in the ED.15

In recognition of these scientific reports, hospitals began to establish treatment algorithms to optimise the early management of patients suffering from multiple trauma.22 Generally, the aim of these algorithms is to guarantee rapid and effective management of the patient’s condition and the individual diagnostic and therapeutic priorities. In addition to urgent procedures such as intubation of the trachea, placement of a thoracic tube, or transfusion, it is vital to recognise potential life-threatening conditions and relevant injuries in order to facilitate immediate interventions without any delay.26,36 The management of emergency patients in the resuscitation room of the University of Heidelberg according to the present algorithms includes in-house attending surgeons, anaesthesiologists, and radiologists in an interdisciplinary team approach. Studies have demonstrated a benefit from the presence of radiologists to interpret the radiodiagnostic findings (especially CT) in the acute period, and therefore radiologists are an essential part of the basic team in our resuscitation room.37,38

The characteristics of the patients in the present study are comparable with those of 2069 patients in the trauma registry of the German Society of Trauma Surgery, showing motor vehicle accidents to be the most common cause of injury, blunt trauma the most common mechanism of injury, with a male—female ratio of 3:1, a mean age of 39 ± 19 years, and an ISS of 22 ± 14.39 In contrast to these patients, our study population showed more head injuries and fewer thoracic injuries, but a comparable incidence of abdominal trauma and extremity injuries.40 Nevertheless, our study population seems to be comparable with the patients in about 100 centers included in the statewide German trauma registry.

On the basis of the trauma registry of the German Society of Trauma Surgery (n = 2069; ISS 22 ± 14), targets have been suggested for the different periods of management of severely injured patients.39 The interval to chest X-ray was 14 ± 20 min, to ultrasound was 13 ± 21 min, and to CCT was 48 ± 34 min.39 In the present investigation, the interval to completion of the chest X-ray in group I was 21 ± 12 min before introduction of the Heidelberg treatment algorithms but was comparable with the findings in group II (12 ± 9 min) after introduction of the algorithm.39 In group I ultra-
sound was already comparable with these targets at $11 \pm 10\text{ min}$ but was even faster in group II ($7 \pm 6\text{ min}$). Moreover, the interval to completion of CCT was already comparable with the registry targets but was significantly further reduced after introduction of the algorithm in group II.\(^{26}\)

Early investigations with patients at two level I trauma centres are comparable with our results.\(^{41}\) At a level I trauma centre, a study of 167 trauma patients investigated the introduction of a multidisciplinary quality management system, which led to reduced intervals from $21 \pm 12$ to $16 \pm 17\text{ min}$ ($p < 0.05$) for completion of basic diagnostic procedures (including X-rays of the pelvis, chest, and cervical spine and ultrasound diagnosis), and from $37 \pm 15$ to $26 \pm 6\text{ min}$ ($p < 0.05$) for CCT in patients suffering from severe traumatic brain injury. The demographics and injury severity of the 90 patients (ISS $20 \pm 16$, age $41 \pm 20\text{ years}$) before and 77 patients (ISS $21 \pm 16$, age $37 \pm 18\text{ years}$) after the implementation of the multidisciplinary quality management system were comparable to our study population. In contrast to our study, that investigation showed non-significant reduction in the intervals from the patient’s admission to the start of emergency surgery ($74 \pm 46\text{ min}$ versus $43 \pm 24\text{ min}$) or to operations ($116 \pm 45\text{ min}$ versus $104 \pm 38\text{ min}$) after introduction of the management system.\(^{41}\)

The introduction of a similar multidisciplinary quality management system at another level I trauma centre including 325 patients, 170 patients (ISS $24 \pm 18$, age $39 \pm 21\text{ years}$) before and 150 patients (ISS $20 \pm 16$, age $38 \pm 21\text{ years}$) after, also showed a reduction in the intervals from $21 \pm 11$ to $14 \pm 6\text{ min}$ ($p < 0.001$) for completion of basic diagnostic procedures (including X-rays of the pelvis, chest, and cervical spine and ultrasound diagnosis), and from $40 \pm 18$ to $28 \pm 7\text{ min}$ ($p < 0.001$) for CCT in patients suffering from severe traumatic brain injury. In addition, this study showed a significant reduction in intervals from $69 \pm 44$ to $45 \pm 19\text{ min}$ ($p < 0.05$) to the start of emergency operations, and from $128 \pm 45$ to $116 \pm 44\text{ min}$ for other early operations after introduction of the management system.\(^{41}\)

Furthermore, the results of the present study are comparable with findings of other researchers who described an improvement in the early hospital management of patients suffering from multiple trauma after the introduction of problem and priority based clinical sequences.\(^{22,26}\) Keeping these findings in mind, other authors stated that algorithms are a formal presentation of interventional sequences, which implemented excellent practice into the local situation.\(^{22}\) Thus, algorithms are not absolutely rigid guidelines but need to be continuously accommodated to local conditions. As in the present study, algorithms should be created in cooperation with all institutions participating in the early hospital management of emergency and severely injured patients. Algorithms should be adapted to infrastructure conditions and the available radiological techniques.\(^{23,42}\)

One explanation for the time reduction in the resuscitation room could be that the time point when a particular procedure is carried out is defined by an algorithm. Implementation of CT early in the algorithm should be discussed. The importance of whole-body multislice computed tomography for early, sensitive, and comprehensive diagnosis in severe head and brain trauma and abdominal and thoracic injuries has been pointed out previously.\(^{43,44}\) With the introduction of MSCT into clinical routine, this technique plays an essential role in early trauma management in an increasing number of trauma centres.\(^{10,45,46}\) Using MSCT instead of conventional radiodiagnostic tests early in the diagnostic workup gives additional clinically important results that affect therapy in $37\%$ of patients.\(^{47-50}\) Using early MSCT instead of conventional radiodiagnostic tests has also been used for a certain group of trauma victims in the present study.\(^{22,45,51,52}\)

The present algorithm calls for a whole-body MSCT as soon as possible in patients with a history or signs of multiple injuries under the following circumstances: (a) patients suffering from major trauma when immediate life-saving surgical interventions are not indicated, and (b) the patient is intubated and mechanically ventilated (Table 2). However, in order to compare the intervals from the patient’s admission to completion of the radiodiagnostic procedures with other existing studies, only the time up to completing the CCT were reported. Moreover, after performing CCT in some patients, the whole-body MSCT had to be interrupted in order to create a burr hole to relieve increased intracerebral pressure resulting from cerebral oedema, or bleeding in significant head injury. After introduction of the algorithm, CT was performed more frequently in group II than in group I ($62\%$ versus $46\%$, $p < 0.01$). In line with other findings, our results showed that the interval to completion of the CT could be reduced significantly ($55 \pm 27\text{ min}$ in group I versus $32 \pm 14\text{ min}$ in group II; $p < 0.01$). Moreover, only $85\%$ of the most severely injured patients (ISS $> 25$) received an initial CCT (Table 4).

In accordance with the algorithm, this is related to the fact that the remaining $15\%$ patients were referred immediately for a life-saving intervention (e.g., laparotomy after ultrasound) before a CCT could be performed.
Other investigators have already performed whole-body MSCT in the resuscitation room without prior ultrasound and chest X-rays, which resulted in an interval from admission up to completion of the CT of 25 ± 10 min. However, since details of the injury severity, the combination of injuries, and the cause of injury are lacking, the intervals achieved in that study cannot be compared with our findings.

However, the concept of early whole-body CT has been criticised and others have pointed out that it should not be used routinely in the first step in haemodynamically instable patients or in patients suffering from multiple trauma where significant intra-abdominal bleeding requiring immediate laparotomy can be diagnosed by early ultrasound. In addition, MSCT cannot be performed during CPR. Therefore, even with MSCT in the resuscitation room, conventional chest X-rays and ultrasound must also be available. Hence, ultrasound of the abdomen, pleura, and pericardium by a radiologist still comprises the first diagnostic procedure in the Heidelberg treatment algorithm.

After introducing the algorithm we found a significant reduction in in-hospital mortality from 33.3% to 16.7% in the most severely injured patients (ISS ≥ 25, Table 4). This algorithm-dependent mortality reduction is also supported by a study at two other level I centers where implementation of a multidisciplinary quality management system reduced mortality from 12% to 9% and from 21% to 18%. However, these findings need to be confirmed in a larger study population.

Potentially, the algorithm-dependent mortality reduction could be due to the increased incidence of life-saving interventions (19% versus 29%; p < 0.05), and to the higher number of emergency interventions per patient (1.1 ± 0.3 versus 1.3 ± 0.4; p < 0.05), respectively. This may reflect better diagnosis and detection of life-threatening injuries after the introduction of algorithm.

A study at a level I hospital in Basel, Switzerland, investigating 171 patients with multiple injuries in the resuscitation room used a questionnaire in order to analyse 884 persons involved in the initial management. The study showed a potential conflict between surgeons and anaesthesiologists, and inadequate time management. Necessary improvements in sequences of action and use of technical resources and inadequate education were cited most frequently by responders of the survey. With this in mind, the results of the present investigation showed that less time was spent in the resuscitation room after introducing the algorithm. This may be due to the clear time guidelines, the structured course of action, the defined use of technical resources, and, as a result of continuous application of the algorithm, better training of the staff involved. Without having investigated this point specifically, our experience has shown that the staff working in our resuscitation room feel more comfortable since the treatment algorithm was introduced. We believe that our algorithm also optimised the aspects in the evaluation by Gross et al., and, by increasing co-worker satisfaction, the algorithm may also improve team work.

One of the prime aspects of this study is to emphasise that such algorithms should be adapted to the local situation. The concept of an integrated MSCT in the resuscitation room does not seem not to be applicable in our institution. In our algorithm, for instance, an ultrasound investigation of the abdomen according to the FAST concept is a process to detect abdominal bleeding in the resuscitation room before transferring the patient to the MSCT. Therefore, when the patient’s condition and the ultrasound findings suggest significant intra-abdominal bleeding the patient is transferred directly to the operating room without performing a whole-body MSCT beforehand.

It is well known that by defining clinical procedures and pathways intervals can be reduced up to a specific end point (e.g., colorectal surgery, trauma surgery, trauma management). Algorithms and defined clinical pathways provide a clear structure for the order of events and time-dependent actions. Presentation of the Heidelberg treatment algorithm to the staff members and personnel from all participating institutions may have encouraged them to become involved with trauma management. Therefore, it seems to be possible that, besides providing an improved clinical pathway, its introduction alone resulted in more encouraged and interested personnel, which contributed to improved trauma care and the results of the present study.

The present investigation may have some limitations because of its single-centre design. The relatively small number of patients might also represent a point of criticism; however, the results are in line with the findings in other studies that included smaller sample sizes and provide a rational basis for further studies. If algorithms must be adapted to the local situation, a multicentre design does not necessarily seem to be productive. Moreover, the findings of a statistically significant difference in mortality in the most severely injured group, with no overall difference in mortality observed, might be taken as a post hoc analysis, and as such should be interpreted with some caution according to the recently published literature. However, mortality reduction in this group was not confirmed by a post hoc analysis since
the definition of in-hospital mortality is a predefined outcome variable in our study. Moreover, since the mortality of trauma patients correlates with the severity of their injuries, stratifying these patients to different ISS-dependent groups is not new and has been described previously by others. Nevertheless, the results should be interpreted with some caution and be confirmed in a larger study population.

In future, we hope to reduce the time spent in the resuscitation room further by improving our algorithm, optimising the infrastructure, and training our staff in ATLS or ETLS. Furthermore, we are using the data of the ongoing evaluation of emergency patients in the resuscitation room for initiating quality circles and quality control and for performing analyses of complications and errors.

**Conclusion**

In conclusion, the introduction of an algorithm for early management of emergency patients significantly reduced the period to completion of ultrasound, chest X-rays, and cranial computed tomography, and to the start of life-saving interventions in patients admitted to the resuscitation room. Although these findings must be confirmed in a larger study population, the implementation of an interdisciplinary treatment algorithm reduced mortality in the most severely injured patients.

**Conflict of interest**

The authors thereby state that there is no conflict of interest.

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