Vittorio Miele
Margherita Trinci
Editors

Diagnostic Imaging in Polytrauma Patients

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Editors
Vittorio Miele
Department of Radiology
Careggi University Hospital
Florence
Italy

Margherita Trinci
Dept of Emergency Radiology
S. Camillo Hospital
Rome
Italy

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Dedicated to our parents, Antonio and Anna, Maurizio and Margherita

Foreword

According to the statistics, polytrauma is worldwide the fourth leading cause of death in general and the leading cause of death under the age of 40. The exponential growth of the "trauma culture" over the recent years has been driven forward by a significant technological advancement imposed by the digital explosion. This, in connection with an increasing use of multidetector computed tomography (MDCT), has led to the demand for a systematic imaging protocol to be followed in a still more complex pathology. The massive public interest in the main causes of death such as tumors, cardiovascular diseases, and brain diseases has been accompanied by a growing attention focused on the field of polytrauma.

The operators' training is mainly pragmatic and experimental. They dedicate less time to writing and publishing scientific papers than to practical work and are progressively being confronted with saving strategies in events which were up to a few years ago classified as irreversible.

This evolution has led to a growing demand for texts, which integrate the vast knowledge that different competent specialists have accumulated in the field of emergency imaging. What is required is a text presenting a holistic vision acquired by those who work with polytrauma patients every day. These specialists are well aware of the priorities, the existence of pitfalls in apparently simple cases, and the need for an immediate, definitive decision.

Who could be better equipped for such a challenging task than Vittorio Miele and Margherita Trinci after their successful publication of *Imaging Trauma and Polytrauma in Pediatric Patients* and *Imaging Non-traumatic Abdominal Emergencies in Pediatric Patients*.

Vittorio and Margherita have worked with some of the most qualified specialists sharing their daily tasks in the emergency rooms of the largest hospital in Rome, San Camillo, and in one of the most important academic centers for teaching and care, the Careggi University Hospital of Florence. They have dedicated themselves to emergency medicine, exchanging knowledge also with other specialists in the field through correspondence and conferences over the last 10 years.

The original version of this book was revised and Foreword is included in front matter in this version.

I have personally met the editors and several of the authors both as a colleague and as a patient or a relative of others in need of care. And I am well aware that the publication of this book requires great theoretical and practical skills that the authors have managed to put down on paper—a task which is not always easy.

The result of these efforts is a complex and complete edition of *Diagnostic Imaging in Polytrauma Patients*. In 25 chapters this volume provides the practical and theoretical framework of an issue, which implies not only great technical and scientific responsibilities but also a great emotional and media impact.

In every Emergency Department, this volume will certainly be of great use to specialists who must make an instant diagnosis by interpreting images obtained in polytrauma patients. They know that an immediate response must be provided to what has happened from head to toe—like life in the trenches. They can leave their patients with a smile or with regret, knowing that all possible attempts were made. Just like those who have produced this text which I am sure will be present in the bookcase of every radiologist to be consulted daily or to be studied for further cultural education.

Corrado Bibbolino
National Union of the Radiological Area (SNR),
Rome, Italy

Contents

Contributors

Ciro Acampora Department of Radiology, A.O.R.N. A. Cardarelli, Naples, Italy

Manlio Acquafresca Department of Radiology, Careggi University Hospital, Florence, Italy

Gloria Addeo Department of Radiology, Careggi University Hospital, Florence, Italy

Simone Agostini Department of Radiology, Careggi University Hospital, Florence, Italy

Giulia Angelini Department of Diagnostic and Interventional Radiology, University of Pisa, Pisa, Italy

Salvatore Alessio Angileri Diagnostic and Interventional Radiology Department, San Paolo Hospital, University of Milan, Milan, Italy

Giacomo Aringhieri Department of Diagnostic and Interventional Radiology, University of Pisa, Pisa, Italy

Lina Bartolini Department of Radiology, Careggi University Hospital, Florence, Italy

Eva Berardi Department of Radiology, S. Andrea Hospital, Sapienza University, Rome, Italy

Elena Bertelli Department of Radiology, Careggi University Hospital, Florence, Italy

Alessandra Bindi Department of Radiology, Careggi University Hospital, Florence, Italy

Luigi Bonasera Department of Radiology, Careggi University Hospital, Florence, Italy

Marta Brandani Department of Radiology, Careggi University Hospital, Florence, Italy

Luca Brunese Department of Medicine and Health Sciences, University of Molise, Campobasso, Italy

Grazia Loretta Buquicchio Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Giovanna Calabrese Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Raffaella Capasso Department of Medicine and Health Sciences, University of Molise, Campobasso, Italy

Ferdinando Caranci Department of Medicine and Health Sciences, University of Molise, Campobasso, Italy

Gianpaolo Carrafiello Diagnostic and Interventional Radiology Department, San Paolo Hospital, Università degli Studi di Milano, Milan, Italy

Alessandro Castellani Department of Radiology, Careggi University Hospital, Florence, Italy

Valentina Caturano Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Edoardo Cavigli Department of Radiology, Careggi University Hospital, Florence, Italy

Alfonso Cerase, M.D. UOC Neuroimmagini e Neurointerventistica, Dipartimento Scienze Neurologiche e Neurosensoriali, Azienda Ospedaliera Universitaria Senese, Policlinico "Santa Maria alle Scotte", Siena, Italy

Andrea Coppola Unit of Radiology, Insubria University, Varese, Italy

Diletta Cozzi Department of Radiology, Careggi University Hospital, Florence, Italy

Matteo Crippa Vascular Surgery Department, San Paolo Hospital, Università degli Studi di Milano, Milan, Italy

Gavina Cuneo Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Giuseppe D'Amico Department of Radiology, Careggi University Hospital, Florence, Italy

Ginevra Danti Department of Radiology, Careggi University Hospital, Florence, Italy

Riccardo Ferrari Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Chiara Floridi Diagnostic and Interventional Radiology Department, Fatebenefratelli Hospital, Milan, Italy

Sonia Fulciniti Department of Radiology, A.O.R.N. A. Cardarelli, Naples, Italy

Nicola Gagliardi Department of Radiology, A.O.R.N. A. Cardarelli, Naples, Italy

Michele Galluzzo, M.D. Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Giovanni Maria Garbarino Department of Surgery, S. Andrea Hospital, Sapienza University, Rome, Italy

Francesco Gaudino Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Stefano Giannecchini Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Roberto Grassi Department of Radiology, Second University of Naples, Naples, Italy

Giulia Grazzini Department of Radiology, Careggi University Hospital, Florence, Italy

Federico Greco Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Franco Guida Department of Radiology, "Pineta Grande" Hospital, Castel Volturno (CE), Italy

Francesca Iacobellis Department of Radiology, "Pineta Grande" Hospital, Castel Volturno (CE), Italy

Department of Radiology, Second University of Naples, Naples, Italy

Stefania Ianniello, M.D. Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Anna Maria Ierardi Diagnostic and Interventional Radiology Department, San Paolo Hospital, University of Milan, Milan, Italy

Veronica Iodice Department of Diagnostic and Interventional Radiology, University of Pisa, Pisa, Italy

Ettore Laccetti Department of Radiology, "Pineta Grande" Hospital, Castel Volturno (CE), Italy

Monica Marina Lanzetta Department of Radiology, Careggi University Hospital, Florence, Italy

Antonio Leone Istituto di Radiologia, Università Cattolica del Sacro Cuore, Fondazione Policlinico Universitario "Agostino Gemelli", Rome, Italy

Giorgio Loreni Department of Interventional Radiology, Sandro Pertini Hospital, Rome, Italy

Silvia Lorenzi Department of Diagnostic and Interventional Radiology, University of Pisa, Pisa, Italy

Silvia Lucarini, M.D., Ph.D. Department of Radiology, Careggi University Hospital, Florence, Italy

Natalie Lucchina Unit of Radiology, Insubria University, Varese, Italy

Nicola Maggialetti Department of Medicine and Health Sciences, University of Molise, Campobasso, Italy

Alessia De Marco Department of Medicine and Health Sciences, University of Molise, Campobasso, Italy

Maria Gabriella Merola Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Vittorio Miele Department of Radiology, Careggi University Hospital, Florence, Italy

Francesco Morelli Postgraduation School in Radiodiagnostics, Diagnostic and Interventional Radiology Department, San Paolo Hospital, Università degli Studi di Milano, Milan, Italy

Chiara Moroni, M.D. Department of Radiology, Careggi University Hospital, Florence, Italy

Mario Moroni, M.D. Department of Radiology, Careggi University Hospital, Florence, Italy

Barbara Mugellini Department of Diagnostic and Interventional Radiology, University of Pisa, Pisa, Italy

Peiman Nazerian Department of Emergency Medicine, Careggi University Hospital, Florence, Italy

Riccardo Palliola Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Francesca Pancrazi Department of Diagnostic and Interventional Radiology, University of Pisa, Pisa, Italy

Francesca Patella Postgraduation School in Radiodiagnostics, Diagnostic and Interventional Radiology Department, San Paolo Hospital, Università degli Studi di Milano, Milan, Italy

Filippo Pesapane Postgraduation School in Radiodiagnostics, Diagnostic and Interventional Radiology Department, San Paolo Hospital, Università degli Studi di Milano, Milan, Italy

Filippo Piacentino Unit of Radiology, Insubria University, Varese, Italy

Claudia Lucia Piccolo, M.D. Department of Medicine and Health Sciences, University of Molise, Campobasso, Italy

Matteo Pignatelli Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Antonio Pinto Department of Radiology, A.O.R.N. A. Cardarelli, Naples, Italy

Caterina Pizzi Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Silvia Pradella Department of Radiology, Careggi University Hospital, Florence, Italy

Mariagrazia Ramunno Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Claudio Raspanti Department of Interventional Radiology, Careggi University Hospital, Florence, Italy

Marco Rastelli Department of Interventional Radiology, Sandro Pertini Hospital, Rome, Italy

Carmelo Rende Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Federica Romano Department of Radiology, "Pineta Grande" Hospital, Castel Volturno (CE), Italy

Luigia Romano Department of Radiology, A.O.R.N. A. Cardarelli, Naples, Italy

Piercarlo Rossi Department of Diagnostic and Interventional Radiology, University of Pisa, Pisa, Italy

Andrea Sacrini Diagnostic and Interventional Radiology Department, San Paolo Hospital, University of Milan, Milan, Italy

Valeria Saracco Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Mariano Scaglione, M.D. Department of Radiology, "Pineta Grande" Hospital, Castel Volturno (CE), Italy

Sunderland Royal Hospital, NHS Trust, Sunderland, UK

Germano Scevola Department of Interventional Radiology, Sandro Pertini Hospital, Rome, Italy

Serena Schipani Department of Medicine and Health Sciences, University of Molise, Campobasso, Italy

Alessandra Scionti Department of Diagnostic and Interventional Radiology, University of Pisa, Pisa, Italy

Massimo Silva Department of Radiology, A.O.R.N. A. Cardarelli, Naples, Italy

Antonia Sorbo Department of Radiology, "Pineta Grande" Hospital, Castel Volturno (CE), Italy

Alessandro Stasolla, M.D. Diagnostic and Interventional Neuroradiology, S. Camillo Hospital, Rome, Italy

Michele Tonerini Department of Emergency Radiology, Cisanello University Hospital, Pisa, Italy

Caterina Maria Trinci Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Margherita Trinci, M.D. Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Viola Valentini, M.D. Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

Giovanni Battista Verrone Department of Radiology, Careggi University Hospital, Florence, Italy

Marcello Zappia Department of Medicine and Health Sciences, University of Molise, Campobasso, Italy

Giuseppe Zocco Department of Emergency Radiology, Cisanello University Hospital, Pisa, Italy

Management of Polytrauma Patients

1

Vittorio Miele, Gloria Addeo, Diletta Cozzi, Ginevra Danti, Luigi Bonasera, Margherita Trinci, and Roberto Grassi

1.1 Introduction

Trauma is the leading cause of death in people under 45 years old [1], the third most common cause of death in patients aged between 45 and 54 years, and the fifth most common cause of death overall [2]. Approximately 5.8 million people die each year worldwide as a result of injuries (15,000 people die every day), and estimates predict injury deaths to become one of the top 20 leading causes of death in the world by 2030 [1]. Approximately a quarter of the 5.8 million deaths that are referred to as unintentional injuries are from road traffic injuries. Other main causes of death are the result of suicide, homicide, falls, drowning, burns, poisoning, and war [1]. Road traffic injuries represent a significant proportion of worldwide unintentional injury deaths. In 2015, accidents were the fourth leading cause of death in the USA and the leading cause of death for those aged 1–44 although car safety and driver awareness of the use of safety devices have continuously improved. Nearly 200,000 people die from injury each year, which is one person every 3 min [3].

Because injuries usually occur in young healthy individuals (road traffic injuries are the leading cause of death for those aged between 15 and 29 years), they result in potentially life-long disability, significant psychological trauma, and subsequent financial loss [4]. Unintentional injuries were responsible for more than 138 million disability-adjusted life-years lost in 2004, while those from road traffic account for approximately one-third of unintentional injury disability-adjusted life-years in all regions [5]. More than 90% of deaths that result from injury occur in low- and middle-income countries. Comparing high-income countries (North America and Europe) with low-income countries (Africa and Southeast Asia), the mortality rate of unintentional injury deaths is double for low-income countries (65 vs. 35 per 100,000 people), and the rate of life-years disability-adjusted is triple for low-income countries (2398 vs. 774 per 100,000) [4].

V. Miele (✉) • G. Addeo • D. Cozzi • G. Danti
L. Bonasera
Department of Radiology, Careggi University Hospital, L.go G. A. Brambilla 3, 50134 Florence, Italy
e-mail: vmiele@sirm.org

M. Trinci
Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

R. Grassi
Department of Radiology, Second University of Naples, Piazza Miraglia, Naples, Italy

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People with poorer economic backgrounds have higher rates of death from injury and non-fatal injuries; this is due to, among other things, the poorer access to quality emergency trauma care and rehabilitation services. To minimize the effects of injuries, it is necessary to organize a national or regional multidisciplinary trauma system that includes trauma prevention, prehospital care, and improved hospital structures, care, and rehabilitation. The cost for the national medical system in medical care and lost productivity from traumatic injury is astronomical if one includes other nonmedical costs that stem from short-term or permanent disabilities that may result in continuing restrictions on their physical functioning, psychosocial consequences, or reduced quality of life. Road accidents are also a major cause of hospitalization and access to emergency care and can cause severe traumatic disability, such as paraplegia, quadriplegia, and intracranial trauma. Additional expenses resulting from unintentional injuries that occur in high- (87.5%) versus low-income countries (12.5%) is estimated to be 518 billion US dollars [6]. In the case of children, the cost in terms of future job disability and impaired quality of life amounted to 17,000 per child for a total of 347 billion dollars per year [7].

In Italy, over 7000 and 250,000 people died or were injured, respectively, in road accidents or were victims of accidents at work, home, or while partaking in sport events. Trauma is the third cause of death in Italy and the first in young people under 40 years of age; also, it greatly contributes to the number of permanently disabled people. In 2013, the number of road accidents resulting in deaths or injuries in Italy was 181,227; this included 3385 deaths (deaths within 30 days) and 257,421 injured persons [8]. In 2004, road accidents caused less than 1.5% of the annual deaths. More than 40% of deaths included young people between 15 and 24 years, constituting by far the leading cause of death in this age group; therefore, trauma is responsible for extremely serious consequences in terms of human and social costs [9].

1.2 Trauma Definition

Major trauma is defined as a traumatically induced structural injury and/or physiological disruption of a body function determined by an external dynamic force that causes single or multiple life-threatening lesions immediately after an event. Under this aspect, trauma should be considered itself a "vector-borne disease," whose means of transmission is a motor vehicle, firearm, or another blunt object, and which is followed by an admission to an emergency department to formulate a course and treatment.

A major trauma (or polytrauma) is defined when the injury severity score (ISS) is greater than 15; this threshold was first described by Boyd et al. in 1987 as being predictive of 10% mortality [10]. Injury mortality, which was originally described with a trimodal distribution, is now more accurately described as bimodal, since deaths presenting in the immediate and early hospital stages with the advancements in prehospital care, early resuscitation, and critical care have produced near elimination of the late deaths that occur after days or weeks due to sepsis and multiple organ failure.

Immediate deaths, which account for about 60% of all injury-related deaths, are mainly due to non-salvageable injuries, like the rupture of the heart or vessels, and occur immediately after trauma (<1 h), while early deaths account for around 30% and occur during the first 6 h of injury and are due to evolving conditions like hemorrhagic injuries of abdominal organs or expanding intracranial mass lesions [11].

Early deaths are commonly considered preventable given that organization of assistance of trauma patients is optimized at both on-scene and within the hospital by implementing technical and nontechnical skills at various levels.

1.2.1 Emergency and Trauma Care System

The aphorism "*Time is life: the smaller the delay until patients'* admission at the ER, the better the prognosis indeed" summarizes the relationship between shortened prehospital time and improved survival of the traumatized patient well [12]. These authors extensively demonstrated that helicopter medical services are superior to ground medical transportation by referencing historical wars. As a matter of fact, a 52% reduction in the mortality rate was observed in trauma patients treated at the site of injury and transported to the trauma center by air medical transport when compared with standard prehospital management services [12].

The adequacy of initial management of patients from the scene of injury and definitive care are factors that determine prognosis and remote outcome in traumatic events. The term "*golden hour,*" which is ubiquitous in emergency situations, refers to a time period lasting for 1 h or less, during which there is the highest likelihood that prompt medical treatment will prevent death [13]. However, the literal meaning of the term does not imply that survival rates drop off after 60 min. Some use the term to refer to the core principle of rapid intervention in trauma cases rather than the narrow meaning of a critical 1-h time period. It is well established that the patient's chances of survival are greatest if they receive care—both intra- and extra-hospital care—by narrowing the critical time within a short period after a severe injury.

So, if a successful and definite diagnosis and therapeutic evaluation is done within the first hour after trauma (i.e., in the golden hour), the polytrauma patient's chances for survival significantly increase. Thus, therapeutic procedures and diagnostic evaluation must be performed as soon as possible and simultaneously by a multidisciplinary team (trauma team) made up of different professional specialists and technicians who are all dedicated to the patient's management [14].

Effective emergency and trauma care systems—from first aid at the scene of the injury to operating theater trauma surgery—are key factors that affect the success of healthcare facilities in preventing avoidable mortality and morbidity during mass casualty incidents [15]. Building up trauma centers and services to manage with most serious traumas and deliver specialist facilities relatively quickly must therefore be a priority.

Evidence during the last two decades has shown that rapid patient triage followed by transportation to a designated trauma center is associated with a significant reduction in mortality after severe injury compared with transport to a non-trauma center [16, 17]. During initial evaluation, an accurate and timely diagnosis of bleeding and other important injuries is essential to plan and prioritize therapy [18].

For a significant reduction in the number of fatal wounds in a geographical area, it is necessary to develop an integrated system of care. A trauma care system is an organized and coordinated effort to deliver the full spectrum of care to an injured patient from the time of the injury to transport to an acute care facility, and to rehabilitative care. A trauma care system consists of three major providers—pre-hospital, acute care, and rehabilitation—that, when closely integrated, ensure a continuum of care [19] (Fig. 1.1).

1.2.2 Prehospital Care: Triage

Emergency medical services provide out-of-hospital medical care and transport patients to hospitals for extended evaluations by the diagnostic structure. Patients receiving prehospital care have a lower in-hospital mortality compared to those directly managed in the hospital and a reduced length of stay, considerably less than might be expected with; they also experience possible cost savings and reduced risks of long-term disabling sequelae. However, specific situations,

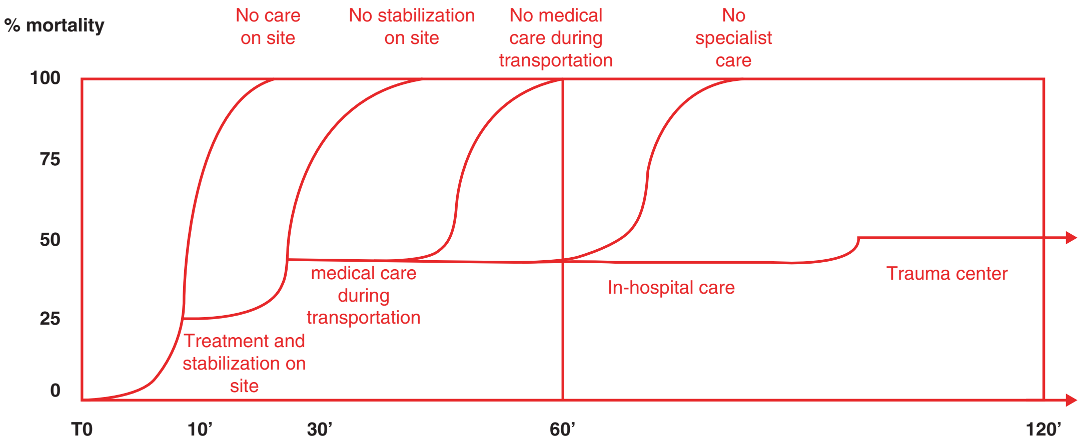

Fig. 1.1 Timely healthcare and best chance of survival. An early continuing healthcare significantly increases the probability of survival in patients with polytrauma. Mortality rates tend to decrease monotonically with life-saving primary care at the accident scene by rapid transfer to the most appropriate hospital for the definitive care. Treatment as early as 1 h or shorter after the traumatic event, especially first aid—prehospital care—platinum 10 min—can help reduce preventable deaths

particularly in the case of inefficiency of emergency department services—mainly in the phase of management and diagnostic classification at the hospital with patients receiving a standard of care that was less than good practice—increased the proportion of preventable trauma deaths.

So, when clinical teams and facilities (e.g., hospital, community, primary care) are organized to meet best practice clinical guidelines and standard services within the trauma system, each patient’s mortality could be significantly reduced [20]. The golden rule would mean that if the right team in a dedicated major trauma center with an efficient organization treats the patient, significant outcome benefits for patients with major trauma will be obtained.

Therefore, the quality of the emergency management system (EMS) as well as response times is critical to life-saving practices. To meet the growing demand of emergency medical services and prevent early deaths, it is crucial for care providers to calibrate and reduce transport time. Once an emergency call is received, the dispatch center identifies the urgency of the call, and on the basis of urgency, the center makes decisions on whether an ambulance or helicopter needs to be dispatched. This depends mainly on the distance to the site of the accident, the accessibility of the site to motor vehicles, traffic intensity, and the right hospital that is able to manage the identified injuries. European health systems provide treatment at the site of the incident, and healthcare professionals are able to correctly apply the principles of patient trauma stabilization and triage procedures and to continue care during transport aboard a land or air ambulance.

The initial assessment is indicated in the guidelines of the advanced trauma life support [ATLS] approach outlined by the American College; the ATLS is a training program for medical providers in the management of acute trauma cases. Nowadays, ATLS is widely accepted as the standard of care for initial assessment and treatment in trauma center.

It suggests to first treat the greatest threat to life. Prehospital trauma care is addressed immediately according to the ABCDE scheme, focusing on the following steps, A: Airway management; B: Breathing, ventilation, and oxygenation; C: circulation and external bleeding control; D: disability, immobilization of the spine, disability, or neurological status; and E: exposure or undressing of the patient while also protecting from hypothermia. There are conflicting views about the most suitable procedure to follow at the scene of the injury—for example, to start with a consistent, high-quality patient care at the accident site or to transfer the injured patient without delay to the trauma unit.

This dualism has had consequences in different countries.

Out-of-hospital care concepts such as "*scoop and run*" (rapid transport to hospital), "*stay and play*" (treatment and stabilization on site), or "*load, go, and play*" (charge quickly and stabilize the patient during the transport) have been compared in recent decades. The "*stay and play*" relief model, which is currently applied in European countries for closed traumas, predicts the presence of medical and paramedic figures aboard.

Staff administering Advanced Life Support (ALS) at the site of trauma results in an average trip time to the hospital of about 18.5 min. In the "*scoop and run*" procedure, where only Basic Life Support (BLS) is provided, emergency trips average 5 min less than the "*stay and play*" procedure [21].

A study undertaken to investigate changes in prehospital care for patients with severe traumatic brain injury demonstrated that the overall mortality rate did not change for the historic BLS cohort (average time on scene 7.5 min) with respect to the current ALS cohort (about four times as long as in the historic cohort) [22]. Regardless of the procedure followed in the rescue of the patient, the best common practice is to carry out life-saving operations on site as quickly as possible and to transport the patient to the most appropriate center in the shortest possible time.

In addition to the aforementioned golden hour, which indicates the importance of early relief and treatment during the first hour after the traumatic event, special attention is paid to the first "*platinum 10 minutes*" in which the causes of preventable deaths (e.g., airway obstruction, hemorrhagic shock) easily lead to death. The first "*platinum 10 minutes*" becomes important to make the golden hour effective and should be distributed as follows to make it fruitful: assessment of the victim and primary survey, 1 min; resuscitation and stabilization, 5 min; and immobilization and transport to nearby hospital, 4 min [23].

This philosophy has been likely borrowed from the military, as many battlefield fatalities occur within the first minutes post injury. Seriously injured patients should have no more than 10 min of scene-time stabilization by emergency medical personnel prior to transport to definitive care at a trauma center [24]. Two possible errors can lead to negative potential consequences at the scene of the rescue that is under- and over-triage of the patient's injury.

Triage protocols were developed by an expert panel and indicate that over-triage is safer than under-triage because if the patient does not require care in a higher level trauma and is unnecessarily transported to such a center, this causes an overutilization of financial and human resources and can lead to overcrowding of the trauma center [25]. Over-triage rates vary in the approximate range 25–50% and may be able to be reduced while maintaining low under-triage rates [26].

Based on presenting signs and symptoms, the protocols recommend patients to one of four alternatives: (1) ambulance transport to an emergency department (ED); (2) transport to an ED by alternative means; (3) referral to a primary care provider (PCP) within 24 h; or (4) treatment at the scene only [27].

According to the "Guidelines for Field Triage of Injured Patients" published by the Centers for Disease Control and Prevention (CDC, 2011), if any of the following alterations that fall into four categories (physiologic, anatomic, mechanism-of-injury, and special considerations) are identified, it is recommended to transport the patient to a facility that provides the highest level of care within the defined trauma system [28, 29]:

Physiologic Criteria

- Glasgow Coma Scale <13
- SBP of <90 mmHg
- Respiratory rate of <10 or >29 breaths per minute (<20 in infant aged <1 year) or need for ventilation support

Anatomic Criteria

- All penetrating injuries to head, neck, torso, and extremities proximal to the elbow or knee
- Chest wall instability or deformity (e.g., flail chest)
- Two or more proximal long-bone fractures
- Crushed, degloved, mangled, or pulseless extremity
- Amputation proximal to the wrist or ankle
- Pelvic fractures
- Open or depressed skull fractures
- Paralysis

Mechanism of Injury

- Falls
  – Adults: >20 ft (one story = 10 ft)
  – Children: >10 ft or two to three times the height of the child
- High-risk auto crash
  – Intrusion, including roof: >12 in. occupant site; >18 in. any site
  – Ejection (partial or complete) from automobile
  – Death in same passenger compartment
  – Vehicle telemetry data consistent with a high risk for injury
- Automobile versus pedestrian/bicyclist thrown, run over, or with significant (>20 mph) impact
- Motorcycle crash >20 mph

Special considerations: EMS personnel must determine whether persons who have not met physiologic, anatomic, or mechanism steps have underlying conditions or comorbid factors that place them at higher risk of injury or that aid in identifying the seriously injured patient.

- Older adults
  – Risk for injury/death increases after age 55 years
  – SBP <110 might represent shock after age 65 years
  – Low-impact mechanisms (e.g., ground-level falls) might result in severe injury
- Children
  – Should be triaged preferentially to pediatric capable trauma centers
- Anticoagulants and bleeding disorders
  – Patients with head injury are at high risk for rapid deterioration
- Burns
  – Without other trauma mechanism: triage to burn facility
  – With trauma mechanism: triage to trauma center
- Pregnancy >20 weeks
- EMS provider judgment

The ideal triage system will direct patients to the appropriate health services for their needs. Updated ambulance technology can speed up response times and improve emergency communications using high-tech wireless networks and making it possible to relay critical patient data to headquarters in real time. Nowadays, there are new apps that allow ambulance personnel to transmit key information to the trauma center, including vital signs and, more importantly, photos or video of the patient's wounds; thus, the trauma center is able to make the necessary preparations for the patient's arrival [30].

EMS service technologies are emerging that provide more options for healthcare providers and make patients' lives better during ambulance transport. Boarded personnel are able to communicate via secure instant messaging with the center to obtain information regarding, for example, traffic and other obstacles; this helps to gain precious minutes when transporting patients to the trauma center.

1.3 Trauma Network

Trauma centers are specially designed to care for the most critically injured patients. New trauma centers are placed geographically with good motorway access, given that the prompt treatment of polytrauma patients by a specialized team has a higher probability of favorable outcomes. Stakeholders and healthcare planners should therefore consider this factor in the development of trauma systems [31]. In a research work comparing the availability of hospital facilities to urban and rural communities, rural communities were found to have higher risk than urban communities because they have less access to trauma centers.

The ACS-COT (Optimal Care of the Injured Patient, by the American College of Surgeons Committee) trauma center classification scheme (Level I through Level IV) is intended to assist communities in their trauma system development [32]. ACS oversees designation of trauma centers in various levels according to hospital resources and educational and research commitments. These categories may vary from state to state and are typically outlined through legislative or regulatory authorities. The different levels (i.e., Level I, II, III, IV, or V) refer to the kinds of resources available in a trauma center and the number of patients that are admitted yearly.

Level I trauma center is a comprehensive regional resource that is a tertiary care facility that is central to the trauma system. In this center, total care for every aspect of injury—from prevention through rehabilitation—is supplied, including educational and research branches.

Level II trauma centers are also able to provide complete treatment for trauma patients, but they do not have educational and research programs. Level III centers have the stabilization and initial resuscitation measures for major trauma patients. Level IV centers assure initial care and have well-functioning protocols for rapid transfer of the patients [33, 34]. Generally, the regional emergency service is organized in specialist centers of excellence (major trauma center [MTC] or "*hub*") located in the regional capitals, which are equipped and staffed to provide care for patients suffering from major traumatic injuries.

An MTC must admit at least 1200 trauma patients yearly or have 240 admissions with an injury severity score of more than 15; they also must be equipped with specialist medical and nursing care. MTCs are directly connected with peripherals, radially diffused, trauma units ("*spokes*") that no longer have to provide major trauma care but still play an essential role in less severely injured patients in whom transfer to an MTC may result in worse outcome.

Despite the longer transport times this entails, triage of major trauma patients to an MTC results in a 30% decrease in mortality in the first 48 h compared with transport to a non-MTC, which may be the closest medical facility [17]. This happened because the key point is not the time to reach a hospital but the efficiency of the final treatment [i.e., interventional radiology (IR) or surgery]. MTC trauma services run 24/7 for diagnostic and interventional services and provide 24/7 whole-body computed tomography (WBCT) by experienced personnel together with the image interpretation as well as 24/7 access for IR services for emergency bleeding control.

1.3.1 Inhospital Care: Primary and Secondary Survey

It is undeniable that application of time-dependent EMS interventions (e.g., airway obstruction, respiratory arrest, external hemorrhage at a compressible site) has potential positive effects on outcomes for most trauma patients. However, it is also plausible that the "golden hour" is primarily dependent on the timeliness of hospital-based interventions (i.e., initiation of definitive care after arrival at an ED) rather than out-of-hospital care [35].

The ATLS method establishes priorities in emergency trauma care by dividing the assessment of each patient's trauma into a primary and secondary survey. The radiologist plays a key role in the early diagnosis of possible life-threatening injuries in the trauma room for defining focused treatments (primary survey) and then in the identification and definition of prognostic scores to assist in stratification of patients in clinical management (secondary survey).

1.3.1.1 The Trauma Resuscitation Team

Once the patient arrives to the hospital, the trauma team takes charge of the patient from the ambulance crew and the traumatized patient is transferred to a trauma room. The trauma resuscitation team consists of physicians, nurses, and allied health personnel, and they are all dedicated to managing the patient. Typically, trauma centers have a single level of trauma, while others may have two or three that are specifically defined in policy and monitored through the trauma quality-assurance process. The size and composition of the team may vary with hospital size, the severity of injury, and the corresponding level of trauma team activation.

A high-level response to a severely injured patient usually consists of a team with the following professionals: general surgeon, emergency physician, anesthetist, radiologist, laboratory technician, radiology technologist, and critical care nurse. The main tasks of the trauma team are the maintenance and improvement of vital functions, diagnosis and early treatment of lesions, and execution of emergency procedures. Major trauma, covering various organs and districts, is certainly the disorder/disease for which a multidisciplinary approach could provide a significant outcome. All levels are based specifically on the hospital resources available to the trauma patient as well as the patient's physiological status. Hospital staff may rely on a report from EMS about the life-threatening injuries identified by the rescue team aboard the ambulance by application of the systematic ATLS primary survey protocol to confirm previously detected vital sign changes.

Therefore, the first step is the activation of the trauma team and to provide immediate resuscitation to the seriously injured trauma patient using hospital resources. In this way, the trauma leader continuously reevaluates the prior ATLS findings since the patient's condition may change (e.g., deteriorate) rapidly. Usually, when a polytrauma patient is identified, the trauma team activates all resources within 15 min of notification.

Each trauma center acts according to internal protocols clearly documented by a "trauma team activation policy" with defined roles and responsibilities for each component. These protocols are subjected to continuous improvements to meet the needs of the plurality of cases encountered. Since there are a variety of hospitals at different organizational levels, no definitive list of trauma team activation criteria exists that is safely employed at all facilities. Each ED that treats polytrauma patients should develop an internal protocol for appropriate multidisciplinary team mobilization on the basis of the internal human and facility-based resources.

In Level I and II trauma centers, the highest level of activation requires the response of the full trauma team within 15 min of arrival of the patient; this includes a surgeon, emergency physician, trauma-trained nurses, imaging department team support, laboratory team support, and respiratory team support.

1.3.1.2 Primary Survey

Historically, the standard of care for trauma patients (i.e., the advanced trauma life support [ATLS] approach) outlined by the American College of Surgeons [36] indicates the guidelines for a reliable evaluation of traumatized patients. The protocol states to identify the most immediate life-threatening conditions and adopt the measures for minimizing the potential risk. The objectives of the initial evaluation of the trauma patient are as follows: (1) to rapidly identify life-threatening injuries, (2) to initiate adequate supportive therapy, and (3) to efficiently organize either definitive therapy or transfer to a facility that provides definitive therapy.

In the primary survey, the sequence and timing of the resuscitation procedures are identified by successive phases following the order A–B–C–D–E (airways–breathing–circulation–disability–exposure/environment). The initial assessment and the arrangement in the primary survey and resuscitation phases can and should be rapid (5–10 min).

A (Airway): Airways and Cervical Spine Protection

The first priority is airway patency by determining the ability of air to pass unobstructed into the lungs. An acute airway obstruction is the leading cause of death in trauma patients. Maxillofacial trauma, neck trauma, and laryngeal trauma are the most common causes of airway dysfunction. As obstruction may partially or totally prevent air from getting into the lungs, and consequent clinical signs ranging from stridor, dysphonia, wheezes, or high respiratory rates together with an altered state of consciousness (e.g., restlessness, stupor, coma) can be a consequence of a respiratory tract obstruction. The most common cause of airway obstruction in the unconscious patient is the hypotonic tongue, but foreign body upper airway obstruction, secretions in the airway, soft tissue damage, and respiratory tract irritation are all potential causes of an obstructed airway. The most basic airway maneuvers are the chin lift and jaw thrust. In a patient who has not been cleared of a cervical spine injury, these maneuvers must be done without significant neck extension. Once the basic maneuvers have been performed, the oral cavity is carefully cleaned, by aspiration of foreign bodies and liquids using electric vacuum suction, which hinders vomit and worsening of the situation. Immobilization of the cervical spine must be instituted until a complete clinical and radiological evaluation has excluded injury (Fig. 1.2).

Oropharyngeal and nasopharyngeal airway devices can provide temporary return of airway patency in an unconscious patient until the airway is definitely secured though intubation. Tracheal intubation is indicated for airway protection (GCS < 9; severe maxillofacial fractures; laryngeal or tracheal injury; evolving airway loss with neck hematoma or inhalation injury) and as a conduit for ventilation (apnea, respiratory distress—tachypnea >30, hypoxia/hypercarbia) [37].

Fig. 1.2 Immobilization of the cervical spine and maneuvers to ensure the patency of the airway

B (Breathing): Ventilation and Oxygenation

A consequential step is the immediate evaluation of the patient's ability to ventilate and oxygenate. A thorough physical examination of the chest should be performed quickly after the initial assessment to rule out possible tension pneumothorax, massive hemorrhage, flail chest, and cardiac tamponade, which are all life-threatening conditions. According to the ATLS, the patient's chest should be exposed to adequately assess chest wall excursion, then auscultation should be performed to assure gas flow in the lungs; then, percussion should be performed to exclude the presence of air or blood in the chest, and finally visual inspection and palpation may detect injuries to the chest wall that may compromise ventilation. A pulse oximeter can be applied to evaluate the efficiency of breathing, and if needed provide supplemental oxygen with bag-valve mask unit or tracheal intubation. In the case of flail chest/severe pulmonary contusion, pneumothorax, or hemothorax, re-expansion of alveolar volume can be obtained by performing endotracheal intubation, mechanical ventilation using a thoracentesis needle, or tube thoracostomy.

C (Circulation): Circulation and Hemorrhage Control

For the hemorrhagic shock in the injured patient who is unresponsive to the usual measures of resuscitation, pericardiocentesis treatment is applied during the primary survey. Circulation is initially assessed by simple observation of the patient, then the peculiar stress and hypovolemia response is taken into account; moreover, the traumatized patient, to compensate for a significant hemorrhage, releases a significant amount of catecholamine and increases cardiac contractility, which increases the heart rate and the systemic resistance. As blood loss progresses, mental status deteriorates, heart rate increases, blood pressure falls, and oliguria is apparent [38]. The estimated blood loss, using vital signs proposed by ATLS to manage the best resuscitation strategy, classifies the state of shock into four classes, according to the blood loss, pulse rate, and pulse pressure [39].

The patient whose persistent vital sign evaluation suggests hypotension is at significant risk for loss of 30–40% of blood volume on presentation and often leads to imminent cardiac arrest. Rapid and accurate assessment of the patient's hemodynamic status based on clinical and hemodynamic criteria is assessed by a combination of parameters: cardiovascular (blood pressure, pulse, pulse pressure); pulmonary (oxygen saturation via pulse oximetry, respiratory rate); skin appearance (color, temperature, capillary refill); CNS (consciousness level); renal-urine output (normal 0.5 cc/kg/h in adults, 1.0 cc/kg/h in children, 2.0 cc/kg/h in neonates).

The estimated blood loss using vital signs proposed by ATLS to manage the best resuscitation strategy classifies the state of shock into four classes according to the blood loss, pulse rate, and pulse pressure [39]:

- Class I: Blood Loss <15% (<750 mL); Pulse rate < 100, normal BP, normal Pulse/Pressure;
- Class II: Blood Loss 15–30% (750–1500 mL); *P* = 100–120, normal BP, decreased PP;
- Class III: Blood Loss 30–40% (1500–2000 mL); *P* = 120–140, decreased BP, decreased PP;
- Class IV: Blood Loss >40% (>2000 mL); *P* > 140, decreased BP, decreased PP.

It is important to note that with the increase of blood loss, particularly when quantification of the loss amount is not feasible (e.g., trauma and occult bleeding), the vital signs that are used to guide fluid replacement in trauma patients with hypovolemic shock due to hemorrhage are not altered. In fact, in Class II, when faced with a circulating blood volume reduction of up to 30%, patients may display blood pressure values that are quite normal but with altered pulse and pulse pressure values. Patients only exhibit tachypnea, tachycardia (HR > 120), decrease in systolic BP, delayed capillary refill, decreased urine output, and a change in mental status for Class III hemorrhages, which are characterized by 30–40% blood loss (1500–2000 mL). For each class, ATLS allocates therapeutic recommendations for example, either the replacement of intravenous fluids (class I–IV) or the administration of blood products (class III–IV) [39].

It is always required to identify the presence of any source of external bleeding with a systemic approach by applying direct pressure; in the presence of uncontrolled bleeding from limbs, pneumatic tourniquets should be immediately used. All polytraumatized patients should be connected to a multi-parameter monitor in order to have a continuous reassessment of the respiratory and circulatory parameters. Two large-bore intravenous lines should be obtained to replace fluids and deliver medications. In case of hypovolemic shock, the infusion plan involves the administration of 250–500 mL warmed boluses; often, a total of 2–3 L of IV fluids is necessary, which will then need to be followed by blood transfusion bolus if hemodynamic stability is not achieved. The positive response to therapy leads to a substantial improvement of vital signs manifested through blood pressure, tachycardia, CNS-mental status normalization, urine output, and organ perfusion improvement [40].

A shock condition in traumatized patients is attributed to hemorrhage until proven otherwise; in relation to the context, of course, different and concurrent causes should be assessed: bleeding from the thorax (massive hemothorax, vascular injury, penetrating cardiac injury); abdomen (solid-organ injury [liver, spleen, or kidney], major vessel injury, or mesenteric bleeding); retroperitoneum (pelvic fracture); long bone fractures (e.g., femur); and also myocardial dysfunction after contusion due to thoracic trauma, or medullary impairment with neurogenic shock (hypotension without increase of heart rate or vasoconstriction) due to head and neck injuries.

D (Disability): Neurological Assessment

A brief neurologic exam is carried out to assess whether a serious head or spinal cord injury exists. This assesses the patient's level of consciousness, papillary size, and reaction and possible lateralizing signs. The level of consciousness is classified according to the Glasgow coma scale (GCS) or the AVPU score. The GCS evaluates the severity of head injury by classifying three different aspects of behavioral response to external stimulation: eye opening; motoric reaction; and verbal response. The score ranges from 3 to 15, where a score of 15 represents a patient's eyes spontaneously opening, obeying commands, and being normally oriented. The worst score is 3 points.

A decreased GCS can be caused by a focal brain injury (i.e., an epidural hematoma, a subdural hematoma, or a cerebral contusion) and by diffuse brain injuries ranging from a mild contusion to diffuse axonal injury [41]. The pupils are also examined for size, symmetry, and reactiveness to light, the spinal cord is assessed for injury by observing the spontaneous movement of the extremities and spontaneous respiratory effort. Oxygenation, ventilation, perfusion, drugs, alcohol, and hypoglycemia may all also affect the level of consciousness. Patients should be reevaluated frequently at regular intervals, as deterioration can occur rapidly, and often patients can be lucid following a significant head injury before worsening.

E (Exposure): Exposure and Thermal Protection

Trauma patients should be completely undressed for a thorough physical examination. Soon after, they should be protected from thermal dispersion. Then, the trauma patient is treated prophylactically with the administration of warmed intravenous fluids, blankets, heat lamps, and warmed air-circulating blankets as needed.

Formulation of the Patient's Severity Index

At the end of the qualitative and quantitative assessment of all phases summarized with the acronym ABCDE, the patient's chance of survival is calculated according to the injury severity score (ISS), which correlates the mortality, morbidity, and hospitalization time after trauma with a number varying between 0 and 75. A major trauma (or polytrauma) is described by an ISS index greater than 15 [42]. In addition to the ISS, many trauma score systems have been developed and used. For instance, the revised trauma score (RTS) [43] is the most widely used although its calculation is too complicated for easy use in the ES [44].

According to the ATLS indications, imaging is helpful during the primary survey, but the use should neither stop nor delay life-saving maneuvers. The inherent instability of the trauma patient in this setting provides a requirement for rapid imaging and accurate, timely interpretation. It is especially relevant because evaluation by history and clinical examination alone has been shown to result in misdiagnosis in 20–50% of patients with blunt polytrauma [45]. A common concept in trauma management that early intervention leads to improved outcomes is that of the "golden hour" [36]. Since its inception, the advanced trauma life support (ATLS) program has been adopted in over 60 countries and has repeatedly undergone important changes. Throughout these revisions, the role of medical imaging has evolved. The current iteration of the program includes, after the "ABCDE" of the primary survey, descriptions of a trauma series (plain film radiographs of the cervical spine, chest, and pelvis), a focused assessment with sonography for trauma (E-FAST) examination, and the selective use of MDCT. The secondary survey is essentially a head-to-toe examination with completion of the history and reassessment of progress and vital signs.

Flowchart of Diagnostic Imaging

The diagnostic procedure to be used varies according to the patient's hemodynamic condition. An "unstable" patient is one with blood pressure < 90 mmHg and heart rate >120 bpm, with evidence of skin vasoconstriction (cool, clammy, decreased capillary refill), altered level of consciousness, and/or shortness of breath [46]. In particular, in the case of hemodynamically stable patients (blood pressure > 90 mmHg, pulse <120/min) or patients stabilized after primary resuscitation, full-body CT scan remains the gold standard in the evaluation of injured patients because it allows a detailed view of the body. In contrast, for hemodynamically unstable patients (blood pressure < 90 mmHg, pulse rate > 120/

min), the time-consuming TC scan is not suggested; instead, it is suggested to use X-ray and US during the primary survey [47, 48].

X-rays and ultrasonography provide an initial diagnosis of conditions that can endanger the patient during the diagnostic phase, and in this scenario, the radiologist plays a key role at the emergency setting to provide a first effective diagnostic confirmation of potentially life-threatening clinical situations [49].

During maneuvering, resuscitators are beside the patient who is lying supine, making all the maneuvers to stabilize the patient and carrying out imaging tests such as chest X-ray (CXR) with an AP view, cervical spine X-ray with an LL view, pelvis X-ray with an AP view, and E-FAST scan (extended focused assessment with sonography for trauma). Subsequently, as mentioned above, the hemodynamically stabilized patient undergoes a TC exam that obtains a complete evaluation of all of the body parts (Fig. 1.3).

Emergency Radiology During the Primary Survey

Radiology is the key component of the trauma center, which is a determining factor for the diagnosis and subsequent treatment of trauma injuries, and therefore radiologists are a part of the trauma team. In dedicated trauma services in large hospitals, the team leader of the emergency radiology (ED) directs the evaluation and resuscitation in cooperation with general and orthopedic surgeons, physicians, radiologists, and anesthetists of the ED staff. Neurosurgeons interventions, when significant central nervous system injury is present, can be life saving. A well-integrated team should include all medical professionals involved in the patient's care in addition to the radiologist**.** Often trauma patients are unconscious and uncooperative with medical staff, and this hampers the correct interpretation of the injury mechanism within the right context of the trauma event. This does not properly address the physician and radiologist toward the best-suited technique and protocol for the patient considering the technological resources available to the ED. So, radiologists undergo a significant amount of formal education to provide their expertise to the emergency staff in cooperation with other specialists to improve the quality of patient management.

Logistics of the ED put the patient at the center of the scenario; specialists in the emergency room surround the patient (Fig. 1.4**).** In this context, the role of the radiologist is of primary importance because he is the only specialist that

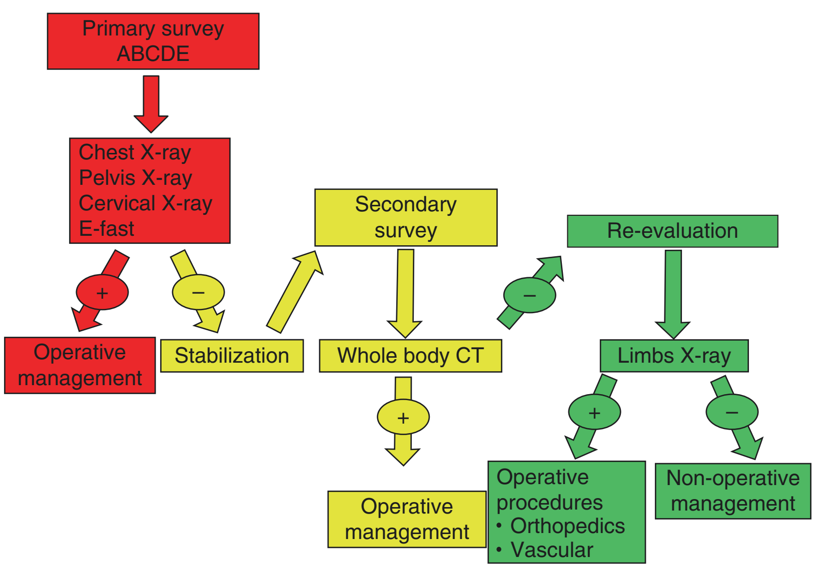

Fig. 1.3 Outline of the current algorithm for the assessment and management of polytraumatized patients

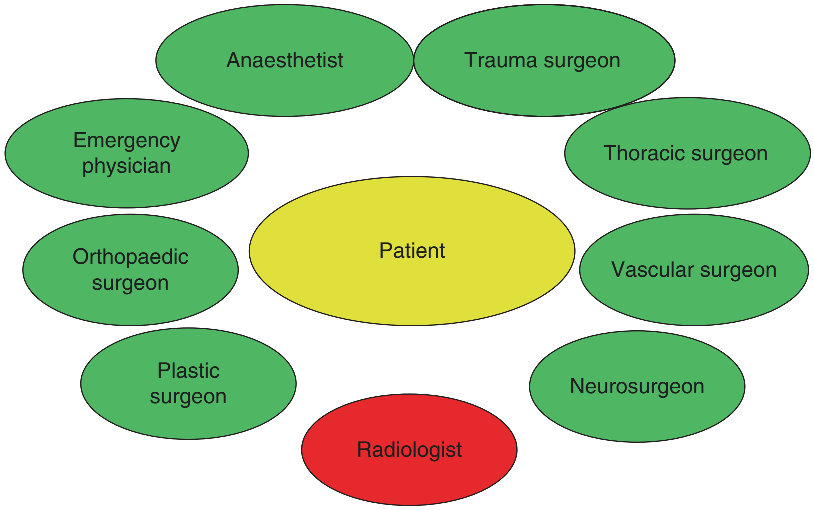

Fig. 1.4 The use of multidisciplinary in-hospital polytrauma teams within an Emergency and Admission Department in a context of concrete and complete collaboration improves patient outcomes

has a full understanding of the final product (the images) and the knowledge of technical equipment and imaging techniques.

Radiology can no longer be viewed as an "add-on" to ED. Indeed, there is no case of urgency or a few cases that are not followed by an imaging act. Emergency radiology is distinguished mostly by the adaptation to any clinical patient's situation, and the radiological response can oftentimes be the most effective, most specific, fastest, and least expensive.

Imaging services therefore must be as rigorous as the other specialties involved in the ED, and they should have the same human resources as other medical services. The powerful informatics systems introduced in the medical arena have allowed to rapidly solving complex health problems and are dependent on the development, for the main part, of the social and political interaction skills of the developer. Therefore, before being a hardware problem, the radiological emergency is a human-based problem.

The clinical radiologist orients and adapts the radiological prescription under its responsibility by an immediate interpretation, and intervening eventually on therapeutics (interventional radiologist). Efficient and optimized care is realized with the cooperation of team members that contribute to the patient's health. Therefore, each qualified "professional" that is directly involved in the diagnostic and therapeutic management will discuss with the radiologist the choice of explorations according to the patient's problem. Efficient patient management requires communication between team members and the radiologist. Each team member supports the patient-centered care to the best of his or her ability.

In order to minimize delay and transport, lifesaving maneuvers need to be performed without stopping resuscitation—this may even require bringing mobile diagnostic apparatus to the patient's bedside. From the emergency room, the patient is transported to the operating block in the shortest possible time; therefore, the CT room must be located within the emergency care area.

Chest X-Ray (CXR)

The plain anteroposterior chest radiograph remains the standard initial exam for the evaluation of the polytraumatized patient in the emergency room. Because of the inaccuracy of clinical signs, important thoracic problems that require possible intervention can be identified using a chest X-ray.

In cases of hemodynamic instability, the presence of respiratory failure (hypoxemia and dyspnea), or after pleural decompression or pleural drainage insertion, an ordinary chest X-ray is recommended. In all cases of blunt trauma, the patient must have a chest X-ray in the supine position in the resuscitation room since unstable spinal fractures have not been ruled out at this stage. In penetrating trauma (penetrating injuries), both from firearms and stab wounds, a chest X-ray should be taken preferably with the patient seated upright to increase the sensitivity for detecting small hemothorax, pneumothorax, or diaphragm injury.

Cervical Spine X-Ray

Cervical spine injuries are the most dreaded among all spinal injuries because of the potential serious neurological sequelae. Significant cervical spine injury is very unlikely in the case of trauma if the patient has normal mental status without neck pain, tenderness on neck palpation, neurologic signs, or symptoms referable to the neck (such as numbness or weakness in the extremities), other distracting injuries, and history of loss of consciousness [50]. However, the radiological series for excluding a cervical spine fracture requires a posteroanterior view, a lateral view, and an odontoid view. The lateral view must include seven cervical vertebrae as well as the C7-T1 interspace, allowing visualization of the alignment of C7 and T1.

According to current evidence, CT imaging of the cervical spine in polytrauma patients has replaced plain film imaging due to its greater sensitivity.

Pelvis X-Ray

Pelvic fractures resulting from motor vehicle accidents and also from falls from heights are very complex, as they imply high-energy trauma that disrupt the solid pelvic ring. These fractures are rarely isolated and are often associated with life-threatening complications such as bleeding (arterial, venous, and cancellous bone).

Up to 60% of mortality rates likely related to significant differences in fracture types have been reported [51]. Hemodynamic instability and multiple organ failure as direct consequences of pelvic hemorrhage have been identified as the primary causes of death following pelvic fracture [52]. In the prehospital exam, signs and symptoms of pelvic injury include deformity, bruising, or swelling over the bony prominences, pubis, perineum, and/or scrotum. Leg-length discrepancy or rotational deformity of a lower limb (without fracture in that extremity) may also appear. Wounds over the pelvis or bleeding from the patient’s rectum, vagina, or urethra may indicate an open pelvic fracture. Neurological abnormalities may also rarely be present in the lower limbs after a pelvic fracture [53]. Screening radiographs of the pelvis are recommended when the mechanism of injury or the degree of hemodynamic instability indicates the possibility of a pelvic fracture. According to the mechanism and severity, pelvic fractures are classified into three main patterns of injuries: anteroposterior compression, lateral compression, and vertical shear [54].

Anterior posterior compression is secondary to a direct or indirect force in an AP direction leading to diastasis of the symphysis pubis with or without obvious diastasis of the sacroiliac joint or fracture of the iliac bone. AP compression injuries cause an increased pelvic volume with any resulting hemorrhage that is unlikely to spontaneously tamponade. Pelvic wrapping therefore should be a priority in early management [55]. The AP projection, recommended by the ATLS program performed during the primary survey provides a large amount of information about the mechanism of injury. In the anterior, the AP projection can identify the presence and extent of the diastasis of symphysis pubis and/or the fracture of the obturator ring. In the posterior, the AP projection recognizes the presence and extent of dislocation of the injured side of the pelvis, dislocations of the sacroiliac joint, or fractures of L5 transverse apophysis. However, this type of projection does not help to evaluate the real dimension of the injury, especially its posterior component [56].

Lateral compression is a lateral compression force that causes rotation of the pelvis inwards, leading to fractures in the sacroiliac region and pubic rami. The lateral fractures are the most common type of pelvic fractures that are mainly