Development and evaluation of a new simulation model for education, research and quality assurance in disaster medicine

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Cover illustration: MACSIM casualty card

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"What I hear, I forget;
What I see, I remember;
What I do, I understand"

Old Chinese proverb,
sometimes attributed to
Confucius

To Carl, Louise, Henrik & Johan and
my parents Birgitta & Sten

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ABSTRACT

Background: The risk for, and incidence of, *major incidents* - situations where available resources are insufficient for the immediate need of medical care to such extent that it involves a risk for life and health - has significantly increased during recent years and continues to increase, parallel to the development in the world. The goal for the health care systems is as much as possible to eliminate or reduce loss of life and health, and physical and psychological suffering, as consequences to such incidents. This requires planning and preparedness, education and training of all potentially involved staff, and also research with development and scientific evaluation of methodology. Since a wide variety of factors influence the outcome of the response to such incidents and all these factors interact with each other, both planning, training and research require simulation models illustrating all these factors and their interactions. Very few simulation models covering all components of the response on a sufficient level of detail to meet the demands necessary for this purpose have so far been available.

Aims: The aims of this thesis were to

- Create and develop a new simulation model with the ability to:
    - Supply information on a sufficient level of detail to provide a base for decisions on all levels and all components of the chain of response, including individual patient management
    - Illustrate all consequences of such decisions
    - Give a measurable result of the response
    - Illustrate the multiplicity and severity of injuries in recent major incidents, such as terrorist actions

- Test and evaluate this model
  - As a scientific tool through comparison of different triage methods in major incident response
  - As an educational tool by development and validation of an interactive training program in major incident response for staff of all involved categories
  - As a tool for quality assurance by testing capacity and preparedness of a major hospital in response to a simulated incident, based on a real scenario

Results: As a method for comparison of triage methods, the simulation model illustrated differences in accuracy and outcome between the two principal methods, anatomical and physiological triage, for different categories of staff with different levels of competence and experience, providing a base for discussion when and where to use the different methods.

As a method for education and training, it provided the base for the start and development of an international training program, generating the establishment of seven international training centers in different countries based on this methodology. Validation of the training program showed that it accurately fulfilled the defined objectives for the training based on experiences from recent major incidents.

As a method for testing capacity and preparedness, it could be used to identify critical limiting factors for surge capacity in a major hospital and also illustrate how these factors interacted with each other and how different functions could be identified as limiting factors at different times during the response. It also provided a base for assessment and improvement of preparedness, organization and performance in major incident response.

Conclusions: The simulation model created, developed and evaluated in this project with the aim to provide a tool for research, training and quality assurance in major incident response:

- Appeared to meet the above defined aims for such a tool within all the studied areas
- Was evaluated to be accurate for its purpose by participating staff of all categories
- Supplied valuable new information and experience within all the tested fields in this thesis

Keywords: major incident, mass casualty, disaster medicine, simulation model, education, quality assurance, triage, surge capacity, MRMI, MACSIM

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SAMMANFATTNING PÅ SVENSKA

Bakgrund

Risken för händelser där tillgängliga resurser är otillräckliga för det akuta vårdbehovet i sådan omfattning att det innebär risk för liv och hälsa - vad som med internationell terminologi betecknas som *major incidents* - har ökat signifikant under de senaste årtiondena och fortsätter att öka parallellt med utvecklingen i världen. Detta ställer ökade krav på sjukvården både i form av planering och beredskap, utbildning och träning samt forskning och metodutveckling. Eftersom ingen sådan händelse är den andra lik och många olika faktorer påverkar utgången av en sjukvårdsinsats och dessutom interagerar med varandra, är simuleringsmodeller en nödvändig komponent i både planering, träning och metodutveckling. Mycket få simuleringsmodeller som täcker alla komponenter i omhändertagandekedjan på den detaljeringsnivå som krävs för detta ändamål finns idag tillgängliga.

Målsättning

Målen med detta avhandlingsprojekt var att:

- Skapa och utveckla en ny simuleringsmodell som kunde
    - tillhandahålla information på tillräcklig detaljnivå för att utgöra grund för beslut på alla nivåer och i alla led av omhändertagandekedjan, inklusive prioritering och behandling av enskilda skadade
    - ge ett mätbart resultat av insatsen
    - illustrera mångfalden och svårighetsgraden av skador i senare tids scenarier som terrordåd, vilka utgör en ökande andel av händelser av detta slag
- Testa, utvärdera och utveckla denna modell
    - som vetenskaplig metod i en jämförelse mellan olika metoder för prioritering av skadade
    - som undervisningsmetod i ett internationellt interaktivt träningsprogram för personal av olika kategorier och
    - som metod för kvalitetssäkring av beredskap, organisation och metodik genom att testa kapacitet och beredskap hos ett större sjukhus vid en simulerad stor skadehändelse baserat på ett i verkligheten inträffat scenario.

Resultat

Som vetenskaplig metod för jämförelse av prioriteringsmetoder illustrerade denna modell skillnader i effektivitet och resultat mellan de två huvudmetoderna anatomisk prioritering (baserad på varje skadas karaktär)

och fysiologisk prioritering (baserad på den skadades fysiologiska tillstånd vid prioriteringstillfället) för personalgrupper med olika kompetens- och erfarenhetsnivå. Resultaten från denna delstudie kan utgöra grund för var i kedjan och för vilken personalkategori olika metoder är bäst lämpade.

Som metod för utbildning och träning kom denna modell att utgöra en bas för utveckling av ett internationellt utbildningsprogram för interaktiv träning av personal av alla kategorier i insats vid händelser av detta slag vilket nu lett fram till bildande av sju internationella centra i olika länder för bedrivande av denna utbildning. Validering av utbildningen visade att den uppfyllde de mål för undervisningen som definierats baserat på analys av erfarenheter av inträffade händelser.

Som metod för test av kapacitet och beredskap kunde denna modell användas för att identifiera de kapacitetsbegränsande faktorerna för omhändertagande av skadade på ett stort sjukhus och även illustrera hur dessa faktorer interagerade med varandra och vilka faktorer som var begränsande i olika faser av insatsen. Resultaten utgjorde också en bas för utvärdering och förbättring av sjukhusets beredskap, organisation och insats vid sådan händelse.

Slutsatser

Den simuleringsmodell som skapats, utvecklats och utvärderats i detta projekt med målet att tillhandahålla ett nytt instrument för forskning, utbildning och kvalitetssäkring inom områdena beredskap, organisation och insats vid omfattande skadehändelser

- uppfyllde definierade mål för ett sådant instrument inom alla de studerade områdena
- värderades av deltagande personal av alla kategorier som adekvat för dessa ändamål
- tillförde i dessa studier värdefull ny information och erfarenhet inom alla de studerade områdena

LIST OF PAPERS

This thesis is based on the following studies, referred to in the text by their Roman numerals.

I. Lennquist Montán K, Khorram-Manesh A, Örtenwall P, Lennquist S. Comparative study of physiological and anatomical triage in major incidents using a new simulation model. *Am J Disaster Med 2011; 6(5): 289-298*

II. Lennquist Montán K, Hreckovski B, Dobson R, Örtenwall P, Montán C, Khorram-Manesh A, Lennquist S. Development and evaluation of a new simulation model for interactive training of the medical response to major incidents and disasters. *Eur J Trauma Emerg Surg 2014; 40: 429-443*

III. Lennquist Montán K, Örtenwall P, Lennquist S. Assessment of the accuracy of the MRMI-course for interactive training of the response to major incidents and disasters. *Accepted for publication, Am J Disaster Med, March 23, 2015*

IV. Lennquist Montán K, Riddez L, Lennquist S, Olsberg AC, Lindberg H, Gryth D, Örtenwall P. Assessment of hospital surge capacity using the MACSIM simulation system - a pilot study. *Manuscript*

CONTENTS

ABBREVIATIONS

AIS	Abbreviated Injury Scale
ALO	Ambulance Loading Officer
ATLS®	Advanced Trauma Life Support
BEME	Best Evidence Medical Education
CBRN	Chemical, Biological, Radioactive, Nuclear
CT	Computer Tomography
CPR	Cardiopulmonary resuscitation
ED	Emergency Department
ESTES	European Society for Trauma and Emergency Surgery
ECTES	European Congress for Trauma and Emergency Surgery
ETS	Emergo Train System®
FAO	Food and Agriculture Organization
GCS	Glasgow Coma Scale
ICU	Intensive Care Unit
ISDM	International Society of Disaster Medicine
ISS	Injury Severity Score
MACSIM	MAss Casualty SIMulation
MI	Major Incident
MIC	Medical Incident Commander
MIMMS	Major Incident Medical Management and Support
MMS	Modified Military Sieve
MRMI	Medical Response to Major Incidents
MS	Military Sieve
NATO	North Atlantic Treaty Organization
OR	Operating room

PAHO	Pan American Health Organization
PHTLS®	Prehospital Trauma Life Support
PTT	Pediatric Triage Tape
RTS	Revised Trauma Score
SALT	Sort-Assess-Lifesaving interventions-Treatment/Transport
START	Simple Treatment And Rapid Transport
STM	Sacco Triage Method
TRO	Triage Officer
TS	Triage Sieve
USG	Ultrasonography
WADEM	World Association for Disaster and Emergency Medicine
WHO	World Health Organization

1 INTRODUCTION

1.1 Major incidents – definitions and risks

1.1.1 Definitions and classification

A wide spectrum of definitions of the term "disaster" has been proposed in the literature [1]. The definition most often referred to is the one adopted by the World Health Organization (WHO), originally launched by Gunn [2]: "*The result of a vast ecological breakdown in the relationship between man and his environment, a serious and sudden (or slow, as in drought) disruption on such a scale that the stricken community needs extraordinary efforts to cope with it, often with outside health or international aid".* This definition restricts the term disaster to only very extensive scenarios such as those caused by disruptions in nature and climate ("natural disasters") and armed conflicts. Simultaneously some countries or regions at lower risk for such events, have used the term "disaster" for "man-made" incidents such as transport incidents (airplanes, trains, buses, ships) as well as intentional terrorist attacks [3]. This illustrates that the terminology is influenced by variations in culture, geography, economy and traditions: what is considered "disaster" in one region may be daily routine in another. This is probably also one reason why it has been so difficult to achieve a generally accepted definition of this term.

In addition, the previously presented and used definitions have been of limited value as a base for decision-making in the process of alert, and also as a base for registration, evaluation and comparison of different events [1].

With the goal to achieve a more practically useful terminology for the health-care sector, a proposal for a new classification has recently been presented [4]. This terminology has with some modification been applied to the MRMI-courses (Medical Response to Major Incidents), used as educational model in the present study (Papers II and III), and will be referred to in this thesis. It is based on the term *Major Incident (MI),* defined as *any situation where available resources are insufficient for the immediate need of medical care to such extent that it involves risk for life and health*. According to this definition, the term MI is not related to any specific number of critically ill or injured, or to any specific level of resources, but to the discrepancy between resources and need. The term should only refer to the acute situation where lack of resources may cause immediate loss of life or severe impairment of health - “chronic” discrepancy between recourses and need should not be classified as MI [4].

The impact on the healthcare system is then related to the **level of MI** [4]**:**

MI Level 1: By adjusting organization and methodology, it is possible to maintain the level of ambition for medical care and save all normally salvageable patients (previously referred to as *compensated incidents*)

MI Level 2: The load of casualties is so high that even with adjusting organization and methodology, it is not possible to maintain the level of ambition = all normally salvageable patients cannot be saved (previously referred to as *uncompensated incidents*)

MI Level 3: As in level 2, but with very large numbers of affected and/or combined with destruction of the infrastructure in a region, requiring *national assistance* from outside the affected region.

MI Level 4: The same as in level 3, but affecting a country where the whole national infrastructure is impaired, or where national resources are insufficient to handle the situation and *international assistance* is needed (the level that corresponds best to the WHO definition of the term “disaster” as referred to above)

The advantage with this terminology is that it can provide a direct practical base for decisions in response to the alert according to Table 1:

Table 1. Actions that should be taken in response to different levels of Major Incident

MI Level	Decision/action
Level 1	Activate disaster plan. Adjust methodology of care: Apply triage according to principles for major incidents; treatments that can wait shall wait, as much as needed adjust level or care to “minimally acceptable standard”. The goal should be to save all “normally” salvageable patients
Level 2	Upgrade level of alert. Adjust methodology as above plus consider addition of category “expectant” to the triage = Casualties with very small prospects of cure are (at least temporarily) given lower priority to make it possible to save patients with a better chance to survive
Level 3	Activate the national coordinating center for major incident response. Prepare for transfer of casualties to health care facilities outside the affected region. Prepare for transfer of staff and supplies to the affected region. If needed, prepare support to re-establish infrastructure in affected region
Level 4	Activate international relief organizations for coordinated international support according to level 3

1.1.2 The risk for major incidents in the modern community

In earlier literature, ”disasters” have been classified as either “natural disasters” caused by changes or disruptions in nature and climate, or as “man-made disasters” caused directly by human beings, or by the technical development caused by human beings. Since changes in nature and climate can be influenced by man and some of the traditionally “man-made” incidents can be influenced by nature and climate, this terminology may no longer be relevant. A proposal for classification according to the MRMI-concept [3] is:

- Incidents consequent to technical development
- Incidents intentionally caused by man
- Incidents caused by changes in nature and climate

Incidents related to technical development

The extensive ongoing technical development has been of great benefit for the community but is also making it more vulnerable to incidents. *Travelling* is continuously increasing with increasing speed, increasing size of transport vehicles and increasing density of traffic. Even if this is followed by increasing measures of safety, economic interests may in many cases be given priority before safety. Thus, this development involves a risk for incidents with increasing numbers of injured and dead on railways, on roads, at sea an in the air. The speed of trains has significantly increased and when accidents occur, the number of severely injured and dead can be considerable [5-7]. The size and speed of ships have increased and the Estonia accident 1994 [8] is an example of the risks connected to this. Even if the mortality of road accidents generally has gone down, 10 bus crashes with a total of 395 casualties occurred only in Sweden during the period 1997-2007 [9]. Travelling by air is among the safest way of travelling today, but crashes still occur, and because of safer planes and more efficient rescue work, the number of surviving injured has increased, increasing the demands on the medical response [10]. Another risk connected to the technical development is the *collapse of buildings or constructions*, often caused by the fact that economy has been given priority before safety [11,12].

Increased *dependence on advanced technology*, such as computer technology and electronic communication, has also paradoxically made the community more vulnerable [13]. This puts high demands on backup systems and training in how to use them, which unfortunately often is given low priority.

The increasing use of different kinds of *hazardous materials* (explosive, flammable, combustible, corrosive, toxic or radioactive) is another risk.

Production and transport of such substances has increased during recent years and may lead to scenarios with very large numbers of critically ill or dead [14,15]. An example of a severe incident with flammable and explosive materials was the San Juanico propane explosion 1984 with more than 7 000 burned casualties, including 600 dead [16]. One of the worst incidents caused by toxic substances was the Bhopal disaster in India 1984 with 520 000 exposed and 16 000 dead [17].

Nuclear power is considered necessary to maintain our standard of living and even with rigorous security, risks for incidents can never be eliminated [18]. An example of this was the earthquake and tsunami in Japan 2011, resulting in damage to several nuclear power plants, presumed to be earthquake safe, with extensive radioactive contamination as a consequence [19].

Another risk-factor is the increasing *gathering of large numbers of people in crowded areas*: (1) permanently as an effect of the on-going urbanization with bigger and more crowded cities, currently developing faster in countries and regions with limited resources and thereby also less capacity for preparedness and response to major incidents [20] and (2) temporarily during gatherings in connection to sport tournaments, festivals or political events which have been identified as an increasing risk during recent years [21-23] and also are identified as potential targets for terrorist attacks.

Incidents intentionally caused by man

Towards the end of the last century, *terrorism* was forecasted by many to be a dominating cause of major incidents in the new century. This was confirmed, in a very apparent way by the World Trade Center terrorist attack on September 11, 2001 [24]. Since then, a continuously increasing number of terrorist attacks have been reported from all parts of the world. Two of the most extensive with regard to the number of dead and injured so far in Europe were the Madrid train terrorist bombings 2004 [25] and the London bombings 2005 [26]. These attacks were well coordinated with bombs exploding more or less simultaneously, on multiple sites during peak traffic intensity, resulting in more than 700 casualties and many fatalities, putting very high strain on the health care systems. Terrorist scenarios also include the risk of using chemical [27], biological [28] and radioactive [29] substances to cause widespread injury to a community. The terrorist strikes with the aim to cause as much death and suffering as possible, with less attention to whether the killed and injured are involved in, or even aware of, the political or religious conflict behind the attack. This means that there is no safe place in the world and all health-care staff has to be prepared, at any time and in any place and without warning, to receive a large number of casualties from a terrorist attack [30]. The increasing ability of terrorist groups to get access to, produce and develop agents with increasing injury-potential has led to more severe scenarios with more casualties and also more severe injuries. This means increasing demands on education and training of health care staff [31-33].

It has been debated if *armed conflicts* should be classified as major incidents, but even if technically developed communities have the aim to give all injured soldiers high-quality medical care, war always involves a risk of having to deal with casualties with limited resources. This is even more valid when war hits communities with limited resources [34]. Also, the recent development in armed conflicts is violence directed increasingly to the un-protected and more vulnerable civilian population, increasing the demands on health care [35] and also involving risk for rescue and health care workers to be intended targets of war [34]. The development in weapon-technology has generated weapons with increasing potential to cause severe injuries, requiring special considerations with regard to treatment. The need of training to deal with these injuries is obvious [34-36].

Incidents caused by changes in nature and climate

Incidents caused by *disruptions in climate and/or nature*, traditionally classified as "natural disasters", can occur suddenly (earth quakes, volcanoes, floods, hurricanes) or slowly (drought or starvation). The World Disaster Report 2007 [37] showed an increase of occurrence of incidents defined as "disasters" of 60 percent during the decade 1997-2006. During this period, the reported deaths from such incidents increased from 600 000 to more than 1 200 000, and the number of affected people from 230 to 270 million.

Among the *sudden onset* incidents, earthquakes are those generating the highest numbers of dead and injured. Major earthquakes during the latest years were the ones in Bam (Iran) 2003 with 40 000 killed and 30 000 injured [38], Sichuan (China) 2008 with more than 70 000 killed [39] and Porte au Prince (Haiti) 2010 with more than 200 000 killed [40]. Earthquakes occurring at sea are often connected to Tsunamis, the worst in modern time being the one in South East Asia 2004 with in total more than 300 000 dead, several thousands of injured and an extensive number homeless. This tragedy also affected Sweden with 543 dead and more than 1500 injured and with many lessons learned with regard to preparedness to support injured citizens in foreign countries [41].

Slow onset disasters like those related to drought and starvation usually strike developing countries where the population already may suffer from malnutrition. The Food and Agriculture Organization (FAO) of the United Nations estimates that man-made climatic changes will cause an increasing number of floods, rain changes and heat-waves that will have impact especially on low and lower-middle income countries, such as in the Sub-Saharan Africa region, where one person in four is undernourished today [42].

Incidents caused by changes in nature should perhaps also include *pandemics* [43] as fulfilling the criteria for major incidents according to the above. A frightening example of this is the currently ongoing Ebola pandemic in West Africa that has caused high pressure on the international relief organizations [44].

Risks for major incidents, summary and conclusions

- The risk for major incidents has increased during recent decades parallel to the development of the community
- Even if certain countries and regions are more exposed to the risk of major incidents, there is no safe place in the world and the major part of the incidents described above can occur at any time and in any place
- It is an important responsibility of the health-care system in every country to be prepared for this and train all potentially involved staff to respond appropriately to these very demanding situations.

1.2 Demands on health care in the response to major incidents

The goal for the health care system in major incidents has been proposed to "as much as possible reduce or eliminate loss of life and health, and physical and psychological suffering as consequences to the incident" [45].

To achieve this goal requires

- Planning and preparedness for (1) relocation of available resources to where they are most needed and (2) mobilization of additional staff and equipment
- Education and training of all potentially involved medical staff in organization of, and performance in, the response
- Scientific evaluation and development of the methodology of response

1.2.1 Planning and preparedness

The need of planning

In all literature dealing with disaster medicine and major incident response, there is a complete agreement with regard to the need of a prepared plan for the response to major incidents [46-49]. When the incident occurs, there is no time for planning. The vast majority of major incidents occur in densely populated areas with short distances to hospitals and often good access to transport facilities, which means that the nearest hospitals may be flooded by casualties very shortly after the incident. As an example, at the Madrid bombings 2004, the nearest large hospital received the first patients within minutes and in total 272 patients from the incident within 2.5 hours [25].

There are a number of vital functions in the response that simply cannot work if they are unprepared [50], for example: A prepared room for a hospital command group with separate external communication lines and equipment needed for coordination of the response; prepared areas in, or connected to, the emergency department for triage and primary treatment of a large number of casualties; a system for simple and fast registration of casualties; a planned strategy for extra ventilator support, since ventilator capacity may be a limiting factor; stocks of supplies for mass casualty management; a planned strategy to get extra supplies, since many supplies are limited to normal immediate needs; backup systems for electricity, water, communication and computer support. There is no time to prepare any of these when the alert occurs and lack of any of these components may cause a collapse of the whole chain of response [50].

The need of simplicity

Even with an agreement with regard to the need of planning, there are varying opinions with regard to the design and extent of the plan. Referring to the above, the plan must be activated and function within a very short time after the alert, which means that there is no time to build up a new organization. The action must be focused on to make adjustment to the already existing organization in order to divert resources to where they are by definition insufficient, i.e. to the treatment of victims [51].

Simplicity has been emphasized as "the key to realistic and accurate planning" [52]. Most incidents occur in densely populated areas, which means that the time between alert and response has to be short [50]. The plan should not be burdened with information that is not absolutely necessary for the primary response and guidelines for specific scenarios can be enclosed as attachments. A plan that is too ambitious and extensive may not be activated before the response is over and is therefore of little or no use. To discover this and adjust the plan to reality requires practical tests and training.

The need for training the plan

If staff of different categories are expected to adapt to and fulfill their function in the plan, they must get opportunity to train for their position in the plan. This is especially important for staff in command and coordination positions and requires a more extensive training, which is a challenge, because covering these positions on an everyday 24-hour base includes a considerable amount of staff [50]. However, all staff acting in the response need to know the structure of the plan, which is best learned through training.

With regard to training of hospital staff, training by bringing casualty-actors into a hospital is expensive and time-consuming and cannot be done without interfering with the daily routine of the hospital [53]. Such training has also been shown not to be cost-effective [54]. If training of hospital staff should be possible in a sufficient extent to cover all involved staff, and to adapt to continuous changes in the hospital organization, it requires simulation models. To develop simulation models that are cost-effective and provide relevant training is a great challenge for the science of disaster medicine.

The need to test the preparedness

Merely the fact that a plan exists is not a guarantee for accurate preparedness for a major incident [55]. Even a simple plan is demanding to make: It must secure that no function is missed in the alert process, that all action cards coordinate with each other and that there is no doubt with regard to who is responsible for decision-making and command on each level and at each point in the chain of response [50]. To do this properly at “the first attempt” without testing it is very difficult. In addition, health care is subject to continuous re-organizations, requiring continuous updating also of the plan for major incident response. It has also been shown that hospital´s self-reported assessments of preparedness and capacity are unreliable [56].

Thus there is a need for objective testing methods and quality assurance of major incident preparedness as for all other functions and procedures within the health care system [50,57].

“Live” tests with casualty actors can be used for very specific purposes such as testing suitability and equipment of facilities for specific functions, but for training it is not cost-effective as a method to test the whole chain of response [50]. This requires again simulation models. Many attempts have been made to develop such methods using computerized models [58,59], virtual reality systems [60,61], and theoretical mathematical models [62,63]. However, there has so far not been any standardized and widely accepted model available for this purpose, which presents another challenge for the science of disaster medicine.

1.2.2 Education and training

The need for training

The review of current risk-scenarios above illustrates that the health care system can be faced with an MI at any time, at any place and without warning, and that the time within the health care system has to respond accurately to preserve life and health can be very short.

For medical staff, such a situation will require ways of dealing with the challenge that differ significantly from their daily routine practice [45]. There may not be sufficient access to, or time to utilize, many of the advanced techniques we are used to having at our disposal. This requires simplified techniques for diagnosis and treatment. The access to specialists may be limited related to the needs, which means that staff has to deal with injuries/conditions outside their own specialty. Lack of supplies may occur, since many supplies are refilled on daily basis. Computer support, on which much of the daily routines are based, may fail, requiring the use of back-up systems. There will also be a much higher need of prioritizing both between patients and between diagnostic and therapeutic measures than in daily medical care.

It is evident that all this requires skills in addition to those required in everyday work, not only on the level of coordination and command, but also on the level of individual patient management [64-67].

If medical staff involved in the response does not have this knowledge and skills, it does not help to have good planning, good equipment and good organization: The result of the response can never be optimal if the staff has not been trained in how to perform in these specific situations. This means that education and training is an equally, or maybe even more, important part of the preparedness than planning, organization and equipment [68,69].

Training of different categories on different levels

As stated above, all staff involved needs knowledge and skills in addition to those needed for routine medical work to respond accurately to a major incident, which creates a need for special courses or educational programs for this purpose [68]. The knowledge and skills required is naturally widely varying between different categories of staff, both with regard to extent and type. Fig 1 is an attempt to illustrate the challenge in designing cost-effective educational programs for different categories of staff at different positions and different levels by a 3-dimensional cube. When designing an educational program or model for a certain category of staff, the following must be taken into consideration:

- The level of action: Operative (triage, diagnosis and treatment of patients), tactical (coordination and command during the response), strategic (planning and administration) or academic (evaluation and development of methodology for planning, performance and training)
- The scenario to deal with: Physical trauma (including extreme temperatures), CBRN (Chemical-Biological-Radioactive-Nuclear) agents, infectious diseases (pandemics) or Public Health (International response to sudden - or slow - onset incidents requiring international relief actions)
- The level of incident according to the scale 1-4 described above [4]

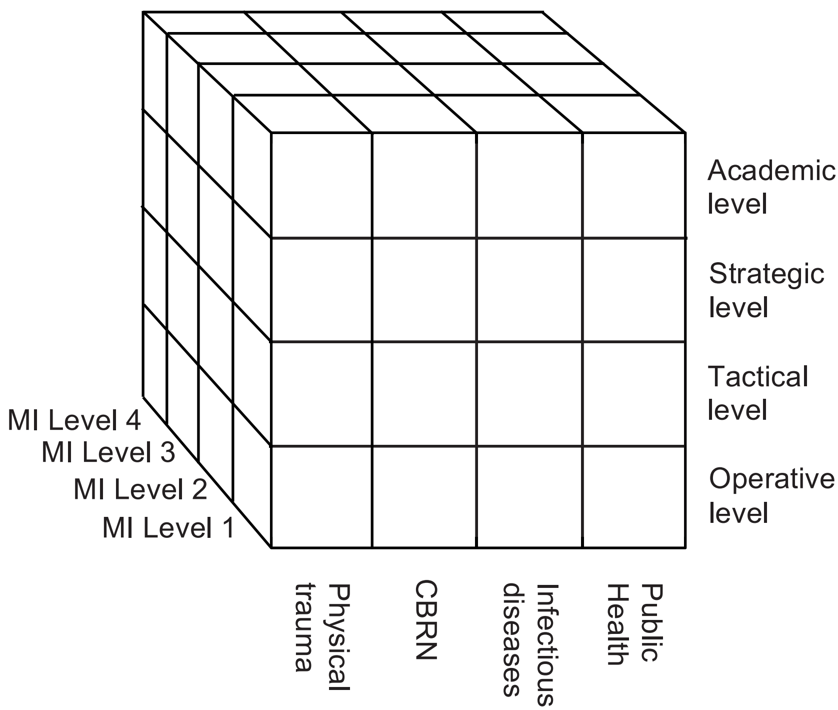

Figure 1. The "3-dimensional cube" for illustration of the need of education and training in major incident response for different scenarios, different levels of competence and different levels of major incidents. For every target group, the field(s) to cover can be inserted in the cube (see further the text) From Lennquist S, with permission.

Since medical staff of all categories can be faced with a major incident at any time in the professional life, basic training in major incident response should be included in the *basic (undergraduate) training* for all health care staff [68]. Transferring this to the “cube” in fig 1 would mean: MI 1, Operative level, Physical trauma (as the most common scenario in most countries). This would be covered by one single block in the cube and require a course of only a few days [70].

On *postgraduate level,* MI-levels 1-3 should be covered combined with additional scenarios depending on local risks. Staff intending to participate in *international relief actions* would need the whole “lower floor” of the cube [70].

Staff in *coordinating functions* would need additional programs on tactical plus, in some cases, strategic level depending on position. Finally, staff on *academic level* needs major parts of the cube, requiring university programs extended over longer periods.

This illustrates that it is not relevant to talk about “a disaster medicine course”. Blocks of the “training cube” have to be selected to make an educational program designed for the goal of the training. All these programs also require training of instructors. To cover all these needs in a cost-effective and accurate way is a responsibility and a considerable challenge for the science of disaster medicine.

The *MRMI-course* (Medical Response to Major Incidents), used as a model in this project, covers MI-levels 1-3 on operative and tactical levels, at the present stage for the scenario “physical trauma” but with on-going plans for inclusion of CBRN scenarios and potential for further extension.

Methodology of training

Skills in clinical disciplines, skills in response to MI cannot be trained in “real “situations. The occurrence of a major incident requires maximal efforts on all positions and is no place for training. This requires access to good training methods [70,71].

Today there is a general agreement on that the best way of learning skills is *learning by doing*. This requires good and accurate models for interactive training in this field. Access to books, book chapters and publications on the internet facilitates pre-course learning. Thus, the time together with teachers and instructors during a course can be better spent on interactive sessions.

A keystone in MI-response is the ability to make rapid and accurate decisions in the whole chain of management [70]. From the level of command (which resources to alert, and how to use them most efficiently?) to the level of management of individual patients, (what to do with this patient on this level and in this situation, how to do it and with which priority?)

Decision making on all levels is based on a lot of information of different kinds. If this information is not accurate compared with the real situation, or not as complete as in the real situation, the decision cannot be properly evaluated [68, 70].

Every decision has effects on the outcome of the response: Consumption of time and resources, outcome with regard to preventable mortality or complications, efficiency in resource-utilization. Accordingly, if these effects not are correctly illustrated, the accuracy of the decisions cannot be properly evaluated [68, 70].

This puts very high demands on a simulation system for training and evaluation of decision-making. Such a system must give correct information on a high level of detail for all components in the chain of response, and it must correctly and in detail illustrate the effects of the decision on the outcome of the response [70].

Interactive training of decision-making can be achieved in different ways: In practical field exercises, in table-top-exercises and by the use of simulation models, live or computerized. A problem with practical field exercises is that they have to be expensive and time-consuming to be able to meet the above given demands on complete input- and output-data. Usually only a restricted number of people gets the opportunity to train. In addition, they usually do not cover more than single components of the chain of response, while coordination and communication between the different components is the most common cause of failure and needs to be trained. The problems with tabletop and simulation models are that so far there have been very few models available fulfilling the criteria given above.

To summarize, education and training of major incident response is a considerable challenge with great potential for further development.

Validation and accuracy of the training

With the increasing awareness of the need for training, a large number of course programs have during recent years been presented in the literature. Many of these have been pure methodological reports, describing the course but without any results, and without an attempt to evaluate or validate the accuracy of training. In other reports, the results have been given by recording the trainee´s opinion of the course, which can be relevant presuming that the trainees have practical experience within the field.

However, the evaluation can be influenced by factors such as how the course is organized and the attitude of the faculty and does not give an entirely objective picture of how the training fulfills the given objectives for the course.

To achieve an objective validation of the accuracy of the training is difficult. The most appropriate method would of course be to compare the trainee´s ability to perform in a major incident before and after the course. This is possible for training programs in clinical skills where the same procedure can be frequently repeated, but no MI is similar to the other and in most places, they are still relatively rare in occurrence.

This is maybe the main reason why so few training programs have been scientifically validated with regard to accuracy of the learning. If decision-makers should be convinced to devote resources and manpower to training in this field, it has to be confirmed that the training fulfills the given objectives. This is another considerable challenge for the science of disaster medicine.

1.2.3 Scientific evaluation and development of methodology

The science of disaster medicine

Because of the difficulty in achieving an internationally uniform definition of the term “disaster”, this term has in the present study been replaced by the recently proposed terminology using “Major Incident” of different levels to classify the severity of an event. It has been discussed if it would be logical to also replace the academic term “disaster medicine” by “major incident medicine”. However, the term “Disaster Medicine” has been considered to be well established with several international journals using this nomenclature. Even if a more practically useful terminology is of benefit as a base for decision-making on operative and tactical level, “Disaster Medicine” is still used for the scientific part of this field [1,46], and will also be used in this thesis.

The need of research

Development and scientific evaluation of methodology is an equally mandatory component of the science of disaster medicine as of all other fields of medicine [1]. Even if disaster medicine by now is a recognized academic field in many countries, it is still a young discipline, established as late as in the mid seventies’ in connection to the foundation of the first international Societies in this field, International Society of Disaster Medicine (ISDM) and World Association for Disaster and Emergency Medicine (WADEM). Since then, however, the development of Disaster

Medicine to a true scientific discipline has gone very slowly [72,73]. It was for a long time mainly a descriptive discipline, reporting experiences from major incidents, but in most cases not in such a standardized and scientific way that it could be used as base for further development. The same mistakes were repeatedly reported without moving forward. However, during the last decade, the number of scientific publications has significantly increased, both in journals specially devoted to Disaster Medicine and in journals for Emergency Medicine, Prehospital Medicine, Trauma and Public Health. Several textbooks have also been published during recent years and the science of Disaster Medicine has been increasingly internationally recognized.

Examples of areas recognized to need urgent attention [46,73,74] are scientific evaluation and quality assurance of planning and preparedness, methodology in major incident response and methodology of education and training. The need of a scientific approach to planning and preparedness as well as to education and training has already been referred to above.

With regard to methodology in major incident response, one important step would be to agree on a standardized way of reporting data from major incidents. Results can then be analyzed and compared related to severity and type of scenario, methodology and outcome as a base for further methodological development. Some proposals for such protocols have been published and also used [74-77], but so far to a very limited extent and there is still no internationally accepted protocol [78].

One way to evaluate the response to a major incident is to identify and define performance indicators for different parts of the response. Proposals for such performance indicators have been published [79-82]. However, such indicators require a test-model supplying (1) the (accurate) information needed as a base for the performance and (2) an accurate illustration of the result of the performance, i.e. the same requirements as for a model for evaluation of planning and preparedness. As already noted above, there has so far not been any widely accepted model available fulfilling these demands. Thus, development of such a model has been a remaining challenge for the science of Disaster Medicine.

A field where an urgent need of a more scientific approach has been recognized is the methodology of triage [83], one of the areas where the methodology in a major incident response perhaps most diverges from the methodology in routine medical care. Since this topic has been used in this thesis to test the developed simulation model as a scientific tool, it will be focus for a more thorough review and analysis below.

1.3 Triage - need of a more scientific approach

1.3.1 Demands on triage

Prioritizing between patients in situations with limited resources is a very demanding task for the health care staff. Especially in the frontline of the response, triage has to be done based on limited access to clinical information, under intense time-pressure and often by staff with limited clinical experience of severely injured or critically ill patients. This creates a demand on simple standardized systems, which relatively easy can be learned and trained.

Triage in MI-situations has to meet the following requirements [84-86].

- The given priority should be continuously re-evaluated along the chain of management
- Standardized systems for triage should be available and trained to make the triage more independent of the level of competence.
- The system used must be adapted to the level in the chain of management on which it is done and the competence of the responder doing it.

1.3.2 Methodology of triage

The two different main principles of triage are "*Anatomical*" and "*Physiological*" triage [83,86,87].

Anatomical triage

Anatomical triage is based on the potential risks and clinical course of the diagnosed or suspected injuries [86]. As example, a penetrating chest injury can be given a high priority based on the potential risk associated with such an injury, even if the patient at the time of triage is in a stable condition.

This requires knowledge and experience enough to make an assessment of an injury based on the often limited information from a rapid clinical examination. An advantage is that this method takes into consideration not only the potential clinical course of the injury, but also the potential effects of treatment, which means that patients with small possibilities to survive can be given a lower priority in MI:s level II and above.

No internationally accepted method for how to perform an anatomical triage exists.

Physiological triage

This method is based on the patient´s physiological condition at the time of examination. The parameters used (breathing, circulation, mental response), are recorded and inserted in an algorithm that automatically gives the priority [83, 86-87]. The advantage with this method is that it can be used also by responders with limited clinical knowledge and experience [87,88]. A disadvantage is that it is only based on the condition of the patient at the time for the triage, not taking into consideration the potential deterioration the injury can lead to. Furthermore, the majority of these physiological methods automatically assign a high priority also to patients with such severe injuries that they are likely to die even with the best of care [89].

1.3.3 Review of available triage methods

Today a wide variety of methods for triage are described in the literature, but no international consensus with regard to selection of method exists [83,84,86,89,90]. Different methods are used in different parts of the world and many of the methods are reported without any objective evaluation or comparison with regard to accuracy and efficiency [83, 90].

Some of the most commonly used physiological triage methods are described below.

Triage Sieve

Triage Sieve (TS) [91] is mainly intended for primary triage, which in most cases is done by the first responders on scene, who often have limited clinical experience of severe injuries. It is based on very simple criteria:

- Can the patient walk?
- Is the patient breathing?
- Respiratory rate?
- Capillary refill? (Alternatively: Heart rate).

The findings according to these criteria are transferred into an algorithm automatically generating the priority. The system is simple to use, but on the same time open to error: Even a patient with a severe internal bleeding, may initially be walking. It may be useful for primary triage under heavy pressure and/or lack of experienced staff, but always has to be followed by secondary triage based on methods providing more information [90].

An alternative model of TS has been proposed by adding criteria for response according to Glasgow Coma Scale, “Military Sieve” (MS). In a study in a field hospital in Afghanistan, Horne et al [92] evaluated and compared MS to the original TS, where MS showed to have a significantly higher sensitivity than TS. MS has then been further adjusted to military conditions by modifying the scores for respiratory- and heart rates, MMS [93]. This further improved the results, but the conclusions were that both these military versions had to be more tested in civilian practice before they could be recommended to replace TS.

Triage Sieve is used for primary triage in many European countries and also in many regions in Sweden. The only reported scientific evaluation of the method in addition to the above was based on retrospective analysis of clinical data from a major incident [83, 94].

Triage Sort

After primary triage with a first "rough" sorting of casualties, there is a need of a more precise method for re-assessment before further transfer - secondary triage. The methodology of physiological triage used for this purpose in most European countries and also in Sweden is Triage Sort. Triage Sort is based on the revised trauma score (RTS), a scoring system with the aim to achieve an early classification of injury severity [95]. The criteria used are:

- Respiratory rate
- Systolic blood pressure
- Neurologic response according to Glasgow Coma Scale (GCS)

Adding the values from these criteria into an algorithm gives a scoring point (Table 1, Paper I) as a base for priority.

Triage Sort gives a safer and more differentiated evaluation of circulatory, and especially neurological, condition. The first is important to early detect internal bleeding in the trunk, the second to be able to follow a course where changes can be a signal on life-threatening intracranial bleeding.

The reliability of the physiological criteria used in Triage Sort has been a matter of controversy. Evidence from the analysis of single physiological parameters suggested that the level of consciousness, systolic blood pressure and respiratory rate were good predictors of death [96]. On the other hand, Garner in a comparative analysis of multiple casualty incident triage algorithms defined respiratory rate as a poor predictor of the need of intervention [97]. Newgard [98], in a critical assessment of the out-of-hospital trauma triage guidelines for physiological abnormalities, concluded that physiological parameters have an unacceptably low specificity and sensitivity.

Even if Triage Sort is the physiological triage method for secondary triage most widely used in our part of the world and is based on a widely accepted scoring system (RTS), its accuracy has so far not been scientifically validated, and it has not been compared to anatomical triage in any scientific study.

START Triage

START Triage (=Simple Treatment And Rapid Transport) [99] is mainly used in the US and based on the criteria ability to walk, airway, respiratory- and heart rate and ability to follow command. It was evaluated in a retrospective study from a train crash 2003 where it was used for prehospital triage [100]. 149 records from 14 receiving hospitals were reviewed. Triage levels appeared in that study to have poor agreement with actual outcome with mis-triage of many patients. One conclusion was the need for more accurate triage methods. START triage has also in a prospective study on casualty-actors been compared with the Sacco triage method (see below).

SALT mass casualty triage

Triage SALT (Sort-Assess-Lifesaving interventions-Treatment/transport) is adapted by the American Colleges of Emergency Medicine and Surgery and also mainly used in the US [101,102]. Triage SALT was evaluated in a prospective study on 50 casualty-actors in a simulated air-crash [103]. Data collection and criteria for assessment of under- and over-triage where however not considered as a sufficient base for evaluation of the accuracy of the triage method in this study [103].

Sacco Triage (STM)

The Sacco triage method (STM) is based on mathematic calculation from empirical data on chance of survival related to physiological parameters and is mainly used in the US [104,105]. STM was in a prospective study on casualty actors and mannequins compared with Triage START [106]. Accuracy of triage decisions was measured in difference between the observed and expected assessment for each patient. Provider´s perception and preferences were observed in surveys (not scientifically designed). The conclusions drawn were that triage was inaccurate and poor with START and STM gave a better result in all objectives. However, a survey among the responders showed that they preferred START. The authors summarizing conclusion was that STM outperformed START and offered significant potential to save lives [106].

Triage Care Flight

Triage Care Flight is based on the same criteria as START Triage with the exception of respiratory rate and is used mainly in Australia. It has been evaluated in a prospective study based on clinical material where it was compared with START Triage and three methods for pediatric triage as described below [107].

Pediatric triage methods

Since normal physiological parameters in children differ from those in adults, triage methods based on physiological criteria cannot be applied to children without adjustments in interpretation. Based on this, methods specially designed for triage in children have been developed. **Pediatric Triage Tape (PTT)**, is a triage tool placed alongside the patient illustrating physiological parameters related to length. PTT is based upon a modification of Triage Sieve and mainly used in the UK and South Africa. **Jump START** is based on START Triage with adjustment of physiological data and used mainly in the US. Both methods have been compared with each other and with START Triage and Triage Care Flight (see above) in a prospective study on a large clinical material of children referred to trauma-centers, triaged using these methods and followed up with regard to outcome and trauma scores [107]. The results showed that all methods had poor sensitivity in identifying seriously injured children. PTT and Care Flight had better results as compared to START and Jump START. A conclusion from the study was a need of more accurately designed pediatric triage algorithms for the future.

1.3.4 Need of a more scientific approach to the methodology of triage

In summary, a wide variety of triage methods exist. Some authors have reported a total number of more than a hundred different methods reported from all parts of the world. Some attempts have been done to objectively compare their accuracy and efficiency [87,97,99,100,102,104,106,108-114]. In the majority of publications, the main conclusion was that more accurately designed and evaluated triage methods are needed.

Jenkins et al in 2008 [83] advocated a more evidence-based approach to triage. Kilner [115] in a review of 1982 papers on triage identified 181 as potentially applicable for evaluation of accuracy. Of those, only 11 were considered relevant and three of those evaluated as “good” [98,104,105]. The conclusion was, in agreement with previous authors, that there was limited evidence for validity of existing triage methods in major incidents. STM was evaluated as unique in including survivability modeling in the triage decision system, but as referred to above, in a comparative study between STM and START, the responders found START easier to use [106]. Challen 2013 [94] in a retrospective analysis from the London bombings in 2007 made an attempt to a comparative study between triage START, Sieve and Care Flight but concluded that even if systematic triage in mass-casualty incidents appeared effective, the amount of missing data compromised conclusions with regard to selection of method.

In summary triage remains one of the major challenges in disaster medicine, which was the reason why we selected this field for testing the new simulation model as a scientific instrument, starting by studying the methodology currently most used in our part of the world.

1.4 Simulation models

1.4.1 Need of simulation models in disaster medicine

This review of the different components of Disaster Medicine, with focus on the needs of further development in different areas, illustrates that there is a need of simulation models in several of these areas:

- For scientific evaluation and development of methodology for planning and response
- For education and training in major incident response
- For validation of training models for this purpose
- For assessment of capacity and preparedness for major incident response

1.4.2 Demands on simulation models

Since all these areas have much in common with regard to the demand for accuracy in such a model, a natural aim should be to develop a model which can cover the needs for all of them.
Based on the above, the demands on such a model should be to:

- Supply information on a sufficient level of detail and of sufficient accuracy to provide a base for decisions on all levels and for all components in the chain of response to a major incident
- Illustrate the consequences of such decisions with regard to consumption of time and resources, efficiency of resource-utilization and result (outcome) of the response related to life and health
- Give a measurable result of the response for the parameters above

Such a model also has to be updated to be able to illustrate scenarios in current major incidents with increased multiplicity and severity of injuries, such as terrorist attacks.

It should also be possible to use it for interactive training of staff of all categories as recognized as the by far best and most efficient way of learning. This eliminates purely theoretical models, as mathematic models and computer programs only for individual use.

The Pan American Health Organization (PAHO) in 2011 published guidelines for developing emergency simulations and drills [116] emphasizing that simulation exercises and drills are among the most useful tools for training of disaster preparedness and to test and evaluate plans for preparedness. According to PAHO, the objectives of simulation should be to:

- "Evaluate the decision-making capacity of personnel responsible for emergency and disaster preparedness and response, in the context of an organization's existing emergency plans and procedures
- Validate the emergency preparedness and response plan for a specific facility or organization
- Test the effectiveness of mechanisms meant to coordinate the response of different sectors and agencies in emergency situations
- Prepare persons who have decision-making authority to manage the crisis and manage information in emergency situations" [116].

Simulation models should facilitate testing disaster plans and preparedness, updating of knowledge, evaluation of decision-making and coordinating mechanisms on intra- and interagency level and evaluation of the participants response [116].

1.4.3 Review of available simulation methods

During the last decade, simulation models have been increasingly used within the health care sector, including the field of emergency preparedness. Olson et al [117] in a comprehensive review of the literature on games and simulations in emergency preparedness 2007-2011 concluded that such methods:

- Could be recommended as an effective training method for teaching emergency preparedness
- During the study period had emerged as an important tool in developing critical competencies related to emergency preparedness and response
- Could be cost-effective planning tools

Issenberg et al [118], in a Best Evidence Medical Education (BEME) systematic review of effective learning through high-fidelity simulation, pointed out the features and uses that led to the most effective learning. The authors of the review selected articles that demonstrated effective learning with regard to improvement in knowledge, skills and attitudes. They found that the highest impact on learning was achieved by:

- Feedback provided by instructors
- Creating opportunities for repetitive practice
- Integrating the simulation in the educational curriculum
- Presenting a range of difficulty levels
- Allowing multiple learning strategies
- Providing a range of clinical scenarios
- Ensuring a safe and educationally supportive learning environment
- Providing both team- and individualized learning
- Defining outcomes
- Validating the simulation tool [118]

There has been an increased use of training and education based on simulation [119,120]. Several studies describe improvement of skills and knowledge in major incident response using simulation techniques, but conclude that there is a need for further development and research [110,121-124].

Simulation supports the development of training decision-making and problem-solving skills in groups [125,126], which is difficult to achieve in a lecture format [127]. Participants can get an opportunity to test already existing and new ways of cooperation through immediate feedback. This supports complex decision-making where different strategies for decisions in different scenarios can be discussed in an environment with cooperative learning [126]. Simulation has also been proposed as a tool to predict and evaluate the impact of different interventional strategies [128,129], support in reducing errors [130] and serve as a guideline for testing and improving disaster plans [116,131,132]. This emphasizes the importance of using a simulation realistic enough to serve as a substitution for an actual event [117].

Reviewing currently available and reported simulation models for this kind of training illustrates that the majority of them focus on only one of the components in the chain of response. As an example, for prehospital health care providers, simulation focus mainly on resuscitation procedures using manikins, films and images, live actors and virtual reality [119]. These simulation exercises are usually done in intra-professional groups and there is a need of more inter-professional simulation training [133-135].

One of the most commonly reported reasons for failure in major incident response is insufficient coordination and communication between involved units [3,24-26,136,137]. To train this coordination and communication, it is necessary to train the whole chain of response simultaneously: Scene, transport, the different components of the hospital, coordination- and command functions. Such training should include also collaborating agencies such as rescue service and police. To do this as "live exercises" with casualty actors handled at the scene, during transport and in the hospitals is possible, but very expensive [78,137-139]. In a report from the US Department of Defense, simulation exercises were calculated to reduce costs to one tenth compared with live field exercises [54]. In addition, live exercises with casualty actors are difficult to standardize and thereby get reproducible results, and they are recognized as not giving optimal feedback to all staff involved [138,140]. They may be used on particular occasions to test practical components of the response, but not for regular training of all staff that needs such training.

Many of the reported models are mathematic models [58,63,141-144] or computer programs for individual use [139,145,146] which may be useful for planning, training or testing parts of the organization, but are usually not developed for testing or interactive training of the whole chain of response including the coordination between units [58,147,148].

In many models, much emphasis has been put on audiovisual effects by using virtual reality technique [61,123,139,149-152]. There is a risk that this is given priority before the scientific information coming out of the model. Such models have also in most cases been restricted to train only single components of the chain of response [139,153].

Many of the reported models focus on so far rather rare causes of major incidents, such as bioterrorism and irradiation [60,123,154-156]. To prepare and train for these kinds of events is of course very important and this is a very suitable field for simulation models. However, it is surprising that so few focus on physical trauma, which is still the most common mechanism of injury in major incidents and an act of terrorism [24-26].

With an increasing number of new simulation models in emergency preparedness and response presented in the literature, it is important to secure that these models really increase the trainees' ability to perform accurately in a major incident. Hsu et al [138,157], in a systematic literature review on the efficiency of hospital staff mass casualty incident training methods, found that “most of the reviewed articles were characterized by significant limitations in design and evaluation of methodology”. The authors stated that there was insufficient evidence to support firm conclusions about the efficiency of specific training methods because of the marked heterogeneity of studies, weaknesses in study design and limited number of exercises reported in each study. They also concluded that more attention had to be directed to evaluating the efficiency of disaster training activities in a scientifically rigorous manner [138,157].

Of currently available simulation systems, the one that was most close to fulfill the demands set up for this project was the Emergo Train System® (ETS) [158]. This system was initially developed by Lennquist 1985, primarily intended for national training of teachers and instructors in Disaster Medicine in Sweden, but was later developed for international use and adapted as training model in many countries in all parts of the world [68,70,159]. It is now owned by the Center for Teaching and Research in Disaster Medicine and Traumatology in Linköping, Sweden. It is a manual system based on magnetic boards and covers the whole chain of response (scene, transport, hospitals, coordination and command). It was one of the first systems to use real consumption of time in exercises and has filled an important function in illustrating the need and benefit of simulation systems for training in Disaster Medicine. When the MRMI-courses were planned, the ETS was primarily considered as a simulation system for the interactive training sessions. However, the symbols for casualties in this system were considered to be difficult to use for illustration of the multiplicity and complexity in many of today´s scenarios, especially scenarios in terrorist attacks.

The casualty symbols also have to be possible to use to illustrate the dynamic pattern of the injuries. The patients´ physiological condition changes continuously after a severe injury, depending on the time passed since injury and interventions done/not done. If the patients’ condition remains the same regardless of this, the trainees´ decisions and performance may not be based on correct information and cannot be evaluated properly. The accuracy in individual patient management is an important component in determining the outcome of the response.

1.5 Summary

The need of a simulation model for methodological research and development, education and training as well as quality assurance in major incident response has been recognized and emphasized. The demands on such a system have been listed and identified as being equal for all these functions. Reviewing available simulation systems, we were not able to identify any currently available system fulfilling all the defined demands. This created the need of making an attempt to develop and evaluate a system with capacity to meet all of these demands.

2 AIMS OF THE THESIS

The over-all aims of this thesis were to:

- Create a simulation model that
    - Supplied information on a sufficient level of detail and of sufficient accuracy to provide a base for decisions on all levels and for all components in the chain of response to a major incident
    - Illustrated the consequences of such decisions with regard to consumption of time and resources, efficiency of resource utilization and result (outcome) of the response related to life and health
    - Could give a measurable result of response for the parameters above
    - Should be updated to illustrate scenarios in current major incidents with increased multiplicity and severity of injuries, as in terrorist attacks
- Test and evaluate this simulation model in a scientific study comparing different methods for triage performed by different categories of staff
- Develop, test and evaluate this simulation model in an interactive program for training of major incident response, covering the whole chain of response and with participation of staff of different categories
- Validate the accuracy with which this training fulfilled the experience-based objectives for the training program
- Develop, test and evaluate this simulation model in a study to test preparedness and measure surge capacity of a major hospital

3 METHODS

3.1 Creation and development of the simulation model

According to the given objectives for the simulation model, it should provide a base for decisions at all levels in the whole chain of response, including also management of individual patients. It should also provide information on the same level of detail as in the real situation, and it should be able to illustrate injuries of the multiplicity and severity met in current scenarios such as terrorist attacks. This resulted in the development of a new simulation system, MACSIM (MAss Casualty SIMulation).

The basic component of the simulation system, the casualty card (Paper I, Fig 1 a, b), was developed to meet these demands. Along the sides of the card, the patient´s condition was illustrated by the physiological parameters (Airway, Breathing, Circulation and Disability). These parameters could simply be changed by the instructor according to the time passed since injury and interventions performed. In the center of the card, the “Exposure” data were given with a simple system of symbols, making it possible to illustrate different injuries. The patient´s original position and response after the incident was also indicated on the card.
As illustrated in fig 2, Paper I, the instructor had for each casualty information on:

- The complete and definitive diagnosis for all injuries
- Times within certain treatments had to be done to avoid risk for mortality and complications (these data were extrapolated from data from corresponding clinical material)
- Outcome in case of optimal treatment, i.e. if the patient had been returned to full health if all possible treatments had been done, and done correctly, also these data extrapolated from data from corresponding clinical material
- Potential need of ventilator treatment
- Trauma scores (ISS, RTS) to correlate outcome to injury severity

Movable triage tags could be attached to the cards, using standard colors (red/yellow/green).

A “bank” of casualty cards was created, based on the type and distribution of injuries experienced at the Madrid bombings 2004 [25]. For the first study (Paper I), 10 casualty-cards were randomly selected from this bank.

To be used as tool for interactive training, the simulation system had to be further developed (Paper II). In addition to the triage tags, a number of treatment tags indicating performed interventions was created (Fig 2, Paper II). Every treatment was connected to a time, based on results from time studies of medical staff doing the same procedures. The access to tags given to the trainee could be adjusted to the access in reality. Along with the further development of the model for training, the number of tags was expanded to also include time-consuming diagnostic procedures. The final number of tags included in the system is illustrated in Table 1, Paper IV.

As a further step in the development, the patient bank was completed with X-ray pictures for all positive findings on plain X-ray, Computer Tomography (CT) and Ultrasonography (USG). The pictures could be showed on a screen by the instructors if/when the trainees ordered the investigations, as a base for decision of treatment strategy. In addition, for patients referred to surgery, schematic drawings of the surgical findings were developed. These could also be showed on a screen as a base for selection of surgical strategy.

Illustration of the management of "normal" patients during the incident required a separate bank of patients not related to the MI, i.e. those patients already being in the hospital at the time of alert, or referred there during the incident. This bank included both ambulatory patients for the emergency department and in-hospital patients of different categories, such as those undergoing planned surgery, needing immediate surgery, undergoing or needing intensive care (Fig 3, Paper II).

To illustrate the consumption of staff and resources of all kinds, movable symbols were added to the system for:

- Staff of all categories and at all levels of the chain of response, prehospital and hospital
- Transport vehicles of all kinds: Ambulances, helicopters, buses; both military and civilian
- Rescue- and police vehicles
- Supplies of different kinds

All casualty cards and symbols were laminated and magnetized and were placed either on magnetic whiteboard screens with drawings and signs illustrating the different components in the chain of response, or (as a further development) on pre-printed magnetic films that could be rolled out and attached to any background.

3.2 Paper I: Comparison of different triage methods

For this first study, the participants were tasked to triage 10 randomly selected patients from the patient bank, using movable triage tags. The simulation model was tested before the study by using it for training of medical staff of different categories, performing physiological and anatomical triage based on the casualty cards.

3.2.1 Selection of test groups

In this quantitative cross-sectional study, we selected three test groups with different levels of skills in disaster medicine:

- Student nurses (n=23)
- Ambulance nurses (n=20)
- Surgeons with experience of trauma (n=30)

3.2.2 Given scenario as background to performance of triage

The participants in the study got the following information as background to their triage: *"Terror attack, bomb detonation, many casualties with blast- and shrapnel injuries. You have arrived with the first ambulance on scene and have the role as Triage Officer (TRO). 10 patients, some of them with life-threatening injuries, have already been carried to the ambulance loading point. Four ambulances with staff are available for immediate transport. The goal for your primary triage is to provide a base for decision with regard to which of these 10 patients that should go with the available 4 ambulances, and then triage the rest of the patients as the base for the order in which they will be evacuated. The Medical Incident Commander (MIC) has decided not to keep additional ambulance crews on scene for treatment, which means that no treatment will be given until the patient gets access to an ambulance. The transport time to available hospitals is 20 minutes"*. The scenario is summarized in a schematic drawing in fig 3, Paper I.

3.2.3 Physiological triage

The model selected for physiological triage in this study was the Triage Sort, which is the method used in Sweden. Triage Sort is based on Revised Trauma Score [95], described above.

When performing physiological triage, the test participants only had access to the physiological parameters indicated on the patient cards, providing a base for Triage Sort. The findings from exposure in the central part of the card were replaced by very short information about the character of injury (Fig 4 a, Paper I). Based on the achieved score, the priority was indicated according the internationally accepted NATO classification T1-T3 where

- T1 = Immediate
- T2 = Urgent but can wait for a shorter period of time and
- T3 = Shall wait

After performing triage, the test participants had to indicate which of the 10 patients they referred to the available ambulances in the first place. Thirty minutes was given for triage and distribution of the patients before the tests were collected.

3.2.4 Anatomical triage

In the next step of the test, the test participants received the same 10 patients, but in different order, with different age and sex, and with information corresponding to exposure in the central part of the card, providing a base for anatomical triage as described above. Since also physiological parameters normally are available in anatomical triage, they were given here, in less detailed form (Fig 4 b, Paper I).

The test participants were given the same instructions for the anatomical as for the physiological triage and the same time for completing the triage and distribution of patients.

3.2.5 Comparing the result with the result of an expert group

An expert group, comprised of 3 experienced specialists in trauma, was used as reference. They all had experience from major incident response. The expert group performed the triage according to the test but with access to the complete diagnosis and clinical course of the injuries (on the backside of the cards).

The given priorities were registered in a databank and the total sum of the groups priority were divided with the number of participants in each group as a mean priority for each patient. The group mean was compared with the priority given by the expert group and the difference between the mean priority given by the test participants and the expert group was registered in SPSS (IBM, New York, NY). It was not taken into the consideration if the test-group had under- or over triaged the patients, each step was considered as a difference.

To calculate the difference in preventable mortality, the 4 patients out of 10, which the test participants had chosen for the 4 available ambulances were registered in Excel and each participant could get the following result:

- 4 of 4 correct patients chosen = 0 % preventable mortality
- 3 of 4 correct patients chosen = 10 % preventable mortality
- 2 of 4 correct patients chosen = 20 % preventable mortality
- 1 of 4 correct patients chosen = 30 % preventable mortality
- 0 of 4 correct patients chosen = 40 % preventable mortality

These 4 patients all had critical injuries but could be saved if they were transported rapidly to a hospital according the prerequisites for the study. Among the other 6 patients, 3 would have died regardless of treatment and 3 would have been salvageable even if not transported among the 4 first patients. This means that the mortality rate could have been between 30 and 70 % and the preventable mortality rate between 0 and 40 %.

3.2.6 Statistical methods

Data were processed using SPSS Version 19.0 (IBM, New York, NY) and descriptive statistics were calculated for all numeric (ratio scale) variables. The outcome was normally distributed and the mean (m) and standard deviation (SD) were analyzed using the independent t-test. ANOVA and the Tukey HSD test were used to compare the results between the groups.

3.3 Paper II: Using the simulation model for interactive training of major incident response

3.3.1 The course

In this study, the simulation system described above was introduced, developed and tested in the postgraduate courses in Medical Response to Major Incidents (MRMI), initiated by members of the Section of Disaster & Military Surgery within ESTES, the European Society for Trauma and Emergency Surgery. The overall objectives given for this course were to:

- Train all components of the chain of response simultaneously, including communication and coordinating between involved units
- Train decision-making on all levels, from command level to triage and treatment of individual casualties

- Provide interactive training with every participant active in his/her role ("learning by doing")

This required access to a simulation system responding to these objectives. The MACSIM system was in comparison with other similar systems selected as the one best suitable for this purpose.

3.3.2 The patient bank

The scenarios for the first MRMI-courses were decided to be terrorist attacks with injuries caused by physical trauma. For this purpose, the patient bank was expanded to 360 casualty cards of the type described above, based on the terror bombings in Madrid 2004 [25] with the same type and distribution of injuries. A number of burn- and head- injuries of different severity were added from other scenarios in order to achieve a complete and covering training in triage. 300 of the "patients" had physical injuries of different severity, 30 were indicated as dead and 30 non-injured and psychologically shocked to include management also of these categories.

3.3.3 Standardized resources and health care structure as base for the simulation

A standardized country was constructed as location for the scenario ("Anyland", Fig 4 Paper II) with a structure that could be representative for most European countries. In the Anyland scenario, the resources for health care and its collaborating organizations were described in detail. A course book with practical guidelines for major incident response in accordance with the course-concept and adjusted to current European standard was published and recommended for pre-course studies [46].

3.3.4 Design of the course venue

The design of the course venue is illustrated in fig 5, Paper II, which shows the complete set-up at the end of the development-period with involvement also of collaborating agencies such as rescue services, police and military. This figure also illustrates a coordinated regional command center with regional medical command, ambulance dispatch, alarm center, rescue service and police located together. This was a result of accumulated experiences during the development period.

3.3.5 The course program

The participants were given reading recommendations and course material to study before the course with the aim to limit lectures and devote the majority of the course to interactive training. The course program was standardized and included one day of preparatory training with the simulation system, combined with a limited number of lectures on organization and methodology in major incident response based on the course concept as referred to above. This first day was followed by two full days of simulation exercises with two different and standardized scenarios. One was conducted in non-office hours with long distances to the nearest hospitals and one during office-hours where the incident occurred in the center of a major city, close to hospitals. The exercises were run with real consumption of time and resources for all functions. All participants were trained in given positions, as closely as possible corresponding to their normal professional position. A thorough evaluation was done after each exercise.

3.3.6 Material

This study included in total nine international MRMI-courses in 6 different countries with a total of 470 participants of different categories (Table 1, Paper II) from 26 different nations.

3.3.7 Evaluation of the response for each training session

The following criteria were used to evaluate the outcome of the response:

- Times for alert and response
- Times for primary and secondary reports
- Rates of over- and under-triage
- Waiting times on scene for staffed ambulances and helicopters
- Preventable mortality and complications, calculated from the data illustrated in fig 2, Paper I, and related to Injury Severity Score (ISS).

3.3.8 Evaluation of the training model

Evaluation of the accuracy and quality of the simulation system was done using standardized evaluation forms given to the participants at the beginning of the training. Assessment of the effects of the training on specific competencies within major incident response was done with the use of self-assessment forms filled in by the participants at the end of the course, using a floating assessment scale. The same methodology was used for assessment of the accuracy of the course as a whole for training of major incident response.

3.3.9 Statistical analysis

In the cross-sectional study on the trainees' evaluation of the accuracy of the training, data were processed using SPSS Version 19 (IBM, New York (NY).

Descriptive statistics including means (M), medians (MD), standard deviations (SD), ranges and interquartile ranges (IQR) was calculated for all numeric variables. Wilcoxon Signed Ranks Test for Matched Pairs was used to analyze pre- and post assessment of knowledge and skills.

3.4 Paper III: Validation of the accuracy of the model for training

3.4.1 Training model

This study was based on the course model described in Paper II. Whereas Paper II described the development process for the course, based on repeated evaluations as a base for adjustments of methodology, the present study (Paper III) was started at the time when the course model was considered fully developed.

3.4.2 Material

The study included five international courses with a total of 235 participants from 23 different countries. Out of these, 102 trained in prehospital functions, 90 in hospital functions and 43 in coordinating functions (command functions on hospital- and regional level). Forty-five percent of these trainees had personal experience from major incidents and disasters.

3.4.3 Original study design

Originally, the design of this study included parallel parameters aimed to validate the accuracy of the training methodology as objectively as possible:

- Comparative test of skills in primary and secondary triage immediately before and after the training,
- Comparison of performance parameters between the first and second day of simulation exercise, using standardized scenarios and standardized protocols for registration of the results of the response
- Forms for self-assessment of knowledge and skills immediately before and after the training, related to the specific aims of the training

A university department for educational research was consulted for design and evaluation of the study. The advice was not to use the results from the first two components above as indicators of the accuracy of the training for major incident response, since it was found not possible to exclude artificial effects of increased skills in using the simulation system. Therefore, the conclusions from the study were only based on the last component, self-assessment of knowledge and skills related to the specific objectives for the training.

3.4.4 Defining specific objectives for the training

The validation process required clearly defined specific objectives for the training in addition to the overall objectives defined at the development of the model (Paper I). These objectives were defined by the international course faculty, based on both extensive collected practical experience from MI:s and literature reviews from recent incidents with large numbers of casualties. These specific objectives for the different categories of staff are listed in Table 1 a-c, Paper III.

3.4.5 Assessment protocols

Since the trainees were recruited to specific positions based on their competencies and served in these positions during the simulation exercises, the effects of the training on their perceived ability to perform was studied separately for prehospital, hospital and coordinating staff. "Coordinating staff" included all trainees in the regional and hospital command centers.

The questions in the protocols were based on the specific objectives for this training for the different categories of staff as referred to above. The accuracy of the questions and the assessment scale, a "floating scale" 1-10, was confirmed by expertise in validation at the Faculty of Educational Research, University of Stockholm.

The pre-course assessment protocols were filled in and collected on arrival to the course venue immediately before the course, and the post-course assessments at the end of the course before closure and diplomas. The trainees were given limited time for this to make it spontaneous and without opportunity to discuss between each other. A code system was used so that the pre-and post-forms for the same participant could be compared.

3.4.6 Statistical methods

To compare pre- and post-course assessments of perceived knowledge and skills was used the Wilcoxon Signed Rank Test for Matched pairs. Data where processed using SPSS Version 22 (IBM, New York, NY) and descriptive statistics were presented as means (M), medians (MD), standard deviations (SD), interquartile ranges (IQR) and P-values.

3.5 Paper IV: Using the simulation model for assessment of hospital surge capacity

In this study, the fully developed simulation model as described in Paper II was used to test the surge capacity and preparedness for major incident response in a major hospital.

3.5.1 The tested hospital

The tested hospital was a 712-bed hospital located on a distance between 2 and 17.7 km from the multiple sites of the simulated incident. This hospital was the Level 1 trauma center of Stockholm and included all specialties involved in trauma management.

According to a proposed modification of the regional disaster plan, based on the experience from the Utøya terrorist shootings- and bombing in Norway 2011 [160]. This hospital was intended to receive all severely injured (red priority) patients from a major incident in the city. This should be made possible by:

- Referring all less severely injured (according to the triage on scene) patients to other hospitals in the city
- Referring all emergency patients not connected to the incident to other hospitals
- When needed, transfer staff with documented trauma competence from another major hospital in the city to this hospital
- When needed, transfer supplies from other hospitals in the city to this hospital through the regional medical coordination center

3.5.2 Design of the test

Exactly one week prior to the simulation (on the same day of the week and on the same time of the day) - a thorough inventory of the hospital to be tested was conducted with regard to:

- The numbers and diagnoses of patients treated in the emergency departments (ED), all different operation theatres (OR), the postoperative units, the intensive care units (ICU) and the emergency wards. These data were recorded in a way that made it impossible to identify any individual patient. In the OR:s, times required for surgery was recorded. In the intensive care units estimations were made if, and if so when, the patients could be transferred to other wards. In the wards estimations were made if and when the patients could be dismissed.

- Numbers and categories of all staff serving in the hospital, and their position in the hospital
- Staff in key-functions, and in specialties involved in the management of trauma patients, not being on duty in the hospital were asked to report the times when they could be available
- Stores of supplies expected to be needed in a heavy load of casualties from physical trauma

Based on this information, the hospital was constructed on magnetic whiteboards illustrating all facilities that potentially could be needed in a major incident with physical trauma:

- Casualty receiving area, ("Triage zone")
- Emergency departments (adult and children) with trauma resuscitation rooms
- Every surgical theatre
- Every postoperative unit
- Every intensive care unit
- X-ray departments
- Emergency wards and wards within potentially involved specialties

All patients in the emergency departments, operation theatres, postoperative units and intensive care units were illustrated by magnetic cards according to the previous inventory, as described above. All staff potentially involved in the incident was handled in a similar way and placed at their position.

Staff normally serving at all the tested positions were recruited to serve at all stations on the boards after a preceding introduction and training on how to use the simulation system.

3.5.3 The scenario

As model for the scenario, the Madrid train bombings 2004 [25] were chosen. This incident was applied to commuter trains in the central part of Stockholm. Bomb explosions occurred with short intervals in trains at four different positions, resulting in 400 casualties and a large number of dead. The injuries were of the same type and distribution as in the Madrid scenario.

Prior to the exercise, an inventory was made at the ambulance dispatch center to register the actual positions of all available transport facilities, times for response, times for ambulance runs to the sites of the incidents and transport times from the sites to the tested hospital. Transport times were also registered between the tested hospital and the other emergency hospitals in case secondary transport would be considered during the exercise. This inventory was also done on the corresponding time of the exercise. Triage and treatment - to the extent that was evaluated to be realistic and accurate in this situation - was indicated on the cards with the priority- and treatment symbols. An initial spontaneous evacuation of mainly less severely injured to the nearest (= the tested) hospital was also included in the scenario.

3.5.4 Running of the test

All casualties given red priority according to Triage Sort [95,161] were transferred to the tested hospital according to the conditions given above. The hospital was intentionally overloaded in order to be able to identify the critical limiting factors for all tested functions.

The casualty cards where delivered to the receiving unit (“Triage zone”) in the hospital ED at the times charted at the ambulance dispatch. Tags were attached to the casualty cards, indicating (prehospital) triage and any treatments performed (when relevant). The casualty cards were registered by secretarial staff on arrival. Hospital primary triage was done by a highly experienced team, distributing the casualties between available resuscitation teams, or for direct transfer to preoperative unit for surgery or to intensive care. In some cases casualties were transferred to an area assigned to patients with lower priority.

The serving staff at all positions then had to examine the patients (= read the casualty cards), make decisions with regard to re-triage, diagnostic procedures and continued resuscitation and treatment, indicate those procedures and transfer the patients to the next position in the chain of management.

Experienced external staff was serving as supervisors at every station with the tasks to:

- Secure that indicated treatments consumed the time and resources needed in reality, with attention to the number and qualifications of the attending staff, represented by staff symbols.
- Indicate worsening (or improvement) of the patients’ condition on the cards according to time passed after injury and treatments done/not done
- Declare patients dead when given time limits for certain treatments were exceeded
- Secure that transport between different positions in the hospital took the time it should have taken in reality according to preceding inventory.

Radiologists had X-ray pictures available for all positive findings on every patient. Thus the referring clinician could review relevant pictures as a base for decision-making. For patients transferred to surgery, schematic drawings of the findings were presented to the operating staff when surgery had started. Based on these they had to select surgical strategy and the supervisors estimated the time needed to complete the procedure according to the strategy chosen. In this estimation, attention was paid to the number and qualifications of the surgical team. Times for anesthesia and preparation, closure and cleaning of theatre were added. A brief surgical report was attached to the casualty cards after surgery.

3.5.5 Recording of data

Observers at every station filled in prepared protocols, recording:

- Times for every patient´s arrival
- Time for start and end of treatment
- Time and destination for departure

All tags for treatments/investigations (Table 1, Paper IV) and all surgical reports were left on the casualty cards after the exercise, making it possible to record all measures taken and also the type and amount of consumed material for these measures, including surgery.

All data from the protocols and casualty cards were put together in a databank. With this document as a base, the patient flow and the casualty-load on different positions related to time from the alert could be determined. By comparing the casualty load with the simultaneously available capacity, the limiting factors for surge capacity at different time intervals could be identified. The analysis with regard to surge capacity was made by an external expert group in order to avoid bias.

The test model was evaluated by combined oral and written evaluations by participating serving and supervising staff. The serving staff also filled in a questionnaire with regard to their opinion of the disaster plan and proposals for changes/improvements based on the test. The disaster committee of the hospital collected these answer as a base for workshops for revision of the plan.

Distribution of the answers in the evaluation form was processed in SPSS Version 22 (IBM, New York, NY) and presented as medians (MD), interquartile ranges (IQR) and minimum-maximum (min-max).

4 RESULTS

4.1 Paper I: Comparative study of physiological and anatomical triage in major incidents using a new simulation model

4.1.1 Specific aims of the study

- To create and develop a simulation model making it possible to evaluate the accuracy and efficiency of different triage methods
- With the use of this model compare the results of physiological (Triage Sort) and anatomical triage performed by medical staff with different levels of skills (a) between the groups and (b) with the results of an expert group.

4.1.2 Results

Three groups of test participants participated in the study: Student nurses (n=23), ambulance nurses (n=20) and surgeons with trauma experience (n=30).

The difference in priority level between physiological and anatomical triage was only significant within the test group of surgeons, who had a better result using anatomical triage ($p<0.001$).

In comparison with the expert group, there were no significant differences between the 3 groups for physiological triage. However, for anatomical triage, there were significant differences both between the student nurses and the surgeons ($p<0.001$) and the ambulance nurses and the surgeons ($p<0.05$). Compared to the expert group, the student nurses had a mean difference of 1.3 (SD±0.48) and the surgeons only 0.52 (SD±0.26).

The result of the distribution of patients to available ambulances showed that the difference between the two methods was significant within all groups and they all had a better outcome using anatomical triage.

The surgeons had a higher preventable mortality with physiological triage than the student nurses, although the difference was not significant. The group that made the best outcome from physiological triage was the ambulance nurses who had a significantly better result than both student nurses and surgeons.

Using anatomical triage, there was a significance ($p<0.001$) between student nurses and surgeons, where surgeons had a much better outcome. The differences between the rest of the groups were also significant ($p<0.05$).

4.1.3 Conclusions

- The model developed for this study made it possible to compare different methods of triage and also triage performed by staff of different levels of training and experience.
- Anatomical triage gave in this study for all test groups significantly better results than physiological triage with regard to calculated outcome and this difference increased with increasing experience.

4.2 Paper II: Development and evaluation of a new simulation model for interactive training of the medical response to major incidents and disasters

4.2.1 Specific aims of the study

The specific aims of this study were to:

- Adjust the simulation model created for, and used in, the first study (Paper I) to be used for interactive training of major incident response
- Develop and continuously evaluate this model in a training program for staff of all categories involved in this response

4.2.2 Results

In total 470 trainees of different categories (Table 2, Paper II), many of them with practical experience from MI response, participating in nine international MRMI-courses were included in this study.

Based on continuous evaluations and accumulated experience, the set-up of the simulation was step-wise adjusted to the present model, including also collaborating agencies, such as rescue service and police, both on scene and on superior command level.

The accuracy of the simulation cards for this purpose was by 63 % of the trainees evaluated as “very good” and by 33 % as “good, the 2 highest out of 6 given alternatives.

Based on the same alternatives, the trainees ranked the quality of the two days simulation exercises: For the first day 69 % "very good" and 26 % "good", for the second day 77 % "very good" and 21 % "good" which means that more than 95 % of the trainees selected the two highest of the six alternatives on the scale. The vast majority (94 %) preferred two full days of simulation exercises.

The participants ranking of to which extent the course increased their competencies related to the given objectives showed on a scale 1-5 for prehospital staff an average of 4.25 ± 0.77 and for hospital staff 4.25 ± 0.72. The accuracy of the course for training of major incident response was on a scale 1-5 by prehospital staff evaluated as 4.35 ± 0.73 and by hospital staff 4.30 ± 0.74.

With regard to evaluation of the effect on the training on specific competencies, the prehospital responders on a floating scale 1-5 ranked the course as increasing their competences in decision-making with regard to command and coordination on scene with 4.15 ± 0.70 (MD 4, IQR = 1). The corresponding figures for primary triage on scene were 4.40 ± 0.76 (MD 5, IQR = 1), decision-making regarding resuscitation and primary treatment on scene 4.21 ± 0.69 (MD 4.0, IQR=1), secondary triage on scene 4.36 ± 0.62 (MD 4, IQR = 1) and decision-making with regard to triage and destination 4.11 ± 0.83 (MD 4, IQR = 1) (Table 3a, Paper II).

The corresponding figures for hospital trainees were for command and coordination 4.21 ± 0.68 (MD 4, IQR = 1), primary triage in hospital 4.30 ± 0.67 (median 4, IQR=1), resuscitation and primary treatment 4.14 ± 0.94 (MD 4.0, IQR=1) and secondary triage in hospital 4.28 ± 0.77 (median 4, IQR = 1). The increased ability to identify and understand the critical factors for hospital surge capacity was on the same scale ranked as 4.30 ± 0.80 (MD 5, IQR = 1) (Table 3b, Paper II).

The accuracy of the course as a whole for training of major incident response using the same scale was by prehospital staff ranked as 4.35 ± 0.73 (MD 4, IQR=1) and for hospital staff as 4.30 ± 0.74 (MD 4, IQR=1) (Table 4, Paper II).

4.2.3 Conclusions

- The simulation system tested in this study could, with adjustments based on accumulated experience and evaluations, be developed to a tool for training of major incident response, meeting the specific demands on such training based on recent experiences from major incidents and disasters.

- Experienced trainees in several courses evaluated the methodology to be accurate for this training, markedly increasing their perceived knowledge and skills in fields of importance for a successful outcome of the response to a major incident.

4.3 Paper III: Validation of the accuracy of the MRMI-course for interactive training of the response to major incidents and disasters

4.3.1 Specific aim of the study

The specific aim of this study was, with the use of pre- and post- course self-assessment of the trainees' perceived competencies, related to experience-based specific objectives for the training, to validate the accuracy of the training for major incident response for the different categories of participating staff.

4.3.2 Results

The assessments were based on a total of 235 trainees: 102 prehospital, 90 hospital and 43 coordinating staff. The overall response rate was 92 % (n=216). However 21 % (n=45) of the responders had filled in the forms in a way that the pre-and post-course-assessments could not be paired and matched with certainty, why they were excluded. That lowered the "effective" (usable) response rate to 73 % (n=171 out of 235).

Tables 1-3 illustrate the differences in pre-and post-course self-assessments for the prehospital staff (Table 1, Paper III), hospital staff (Table 2, Paper III) and staff in coordinating functions (Table 3, Paper III), expressed in mean and standard deviation ($m \pm SD$) but also as median (md) and interquartile range (IQR) because of the skew distribution on answers. The graphical distribution of these assessments is illustrated in fig 5-7, Paper III.

A significant increase between pre- and post-course assessment was registered for all the studied parameters. The average increase for prehospital staff was 74 % ($p < 0.001$), hospital staff 65 % ($p < 0.001$) and staff in coordinating functions 81 % ($p < 0.001$).

4.3.3 Conclusions

- Self-assessment of perceived knowledge and skills immediately before and immediately after the training showed significantly higher scores after the training than before for all parameters and for all categories of trainees.
- This indicates that the studied course accurately responded to the given objectives, which were based on collected experience from major incidents and disasters.

4.4 Paper IV: Assessment of hospital surge capacity and preparedness using the MACSIM simulation system

4.4.1 Specific aims

The specific aims of this pilot study was to use the simulation model described and evaluated in Papers I-III as a tool to test the capacity of all critical functions in a major hospital responding to a simulated major incident with a scenario based on a real incident.

4.4.2 Results

The first recorded capacity-limiting factor was the number of resuscitation teams that could work parallel in the ED, making it necessary to temporarily refer severely injured to other hospitals after receiving 32 red-priority patients (Fig 9, Paper IV).

At this time, OR and ICU still had considerable additional capacity available and the inflow of casualties could be re-started when the ED had been cleared. Next capacity limiting factor was lack of ventilator-beds in the ICU, which finally stopped further inflow and set the limit for surge capacity in this test (Fig 11, Paper IV).

At this time, there was still residual OR-capacity (Fig 10, Paper IV), which means that with access to more ventilators, the extensive surgical capacity of the hospital could have been further utilized.

A total of 59 surgical procedures were performed, 42 patients were referred to intensive care and 35 patients to wards.

By studying the treatment- and diagnostic tags attached to casualty cards, the needs of supplies for all critical functions could be calculated. By requiring supplies from local hospitals, not involved in the management of severely injured casualties, all needs could be covered.

The test was also used for assessment of the hospitals planning and preparedness for major incident response, which was done based on evaluation forms for all participating staff. The result of this evaluation illustrated several potential improvements based on experiences from the test.

The participants' median ranking of the accuracy of the simulation model was on a floating scale 1-10 for the accuracy as a test model for surge capacity 8 (IQR 1). The ranking of the value of the test for quality assurance of preparedness was also 8 (IQR 1). The median ranking of the staff with regard to how much their participation in the test had increased their ability to respond to major incidents in their functions was 8 (IQR 3).

4.4.3 Conclusions

- The used method, based on a real scenario and run with real consumption of time and resources for all involved functions, gave the information required to define the surge capacity of this major hospital
- The participating staff evaluated the method as accurate for this purpose
- The results illustrate that surge capacity cannot be determined by testing one single function in the hospital, since all functions interact with each other and different functions can be identified as limiting factors at different times during the response
- The used methodology was also evaluated as an efficient method to train hospital staff on all levels and to make an assessment of the hospitals planning and preparedness for the response to a major incident

5 DISCUSSION

5.1 Accuracy of the simulation system

5.1.1 Need of a new system

The selected demands of a new simulation model listed in the aims for this project were based on analysis of the needs in the different fields of the science of Disaster Medicine, as reported above. According to this, such a model should be able to:

- Supply information on a sufficient level of detail and of sufficient accuracy to provide a base for decisions on all levels and for all components in the chain of major incident response
- Illustrate the consequences of such decisions with regard to consumption of time and resources, efficiency of resource-utilization and result (outcome) of the response related to life and health
- Give a measurable result of response for the parameters above
- Be updated to illustrate scenarios in current major incidents with increased multiplicity and severity of injuries, such as in terrorist attacks

It should also be possible to use for interactive training of staff in all categories as recognized as the best and most efficient way of learning. No such system fulfilling these criteria could be identified.

5.1.2 Computer-based or manual technique?

Even if the created system in the continued process of development should be partly or completely based on computer technology, we did the choice to start with a “manual” system, for two reasons: (a) The experience within the research group from manual simulation systems for interactive training was so far very good [70,159] illustrating the benefit of letting staff of all categories work interactively together, training coordination and communication between all functions in the chain of response and (b) before starting the very resource-consuming process of inserting all the data required into computer programs, we wanted a manual model of the system to be fully developed and thoroughly tested.

5.1.3 The casualty card

The basic component of the system was the casualty card. To design such a card supplying all the requested information for diagnosis, treatment and triage, but still possible to handle in a manual simulation system with large numbers of casualties, was a considerable challenge. Several models were tested on medical staff of different categories before the present design was selected.

The card had to supply information of all physiological parameters normally available when examining a traumatized patient. To the traditional ABCD-parameters based on the ATLS®-system [162] and used in the different triage systems, information on peripheral skin temperature and respiratory impairment as stridor, hemoptysis and cyanosis was added. The GCS had to be there, but on the same time attention must be paid to the fact that a complete GCS-scoring by many responders is considered to be too time-consuming for mass casualty situations and many use more simple criteria based on response to talk and pain [163-166]. The present card permits for "Disability" both GCS-scoring and scoring based on simpler criteria.

The "Exposure" part of the card had to be able to illustrate that most casualties from recently reported major incidents have multiple injuries. This is especially relevant in scenarios caused by explosives with pressure-related (blast) injuries combined with multiple fragment injuries [25,26]. The symbol system used for this purpose has been shown possible to learn fast by the trainees. Before every course, a training session of 1-2 hours was conducted for training with the cards.

It is very important that parameters can be changed by the instructor based on the time passed since the injury and treatments performed/not performed (fig 2). This is a very important task of the instructor based on access to a complete description of the injuries (Fig 2, Paper I). The patients' condition after a severe injury is dynamic and may change very rapidly. It is a common mistake in simulation exercises of different kinds not to illustrate this properly and thereby missing the important message about the need of making repeated assessments.

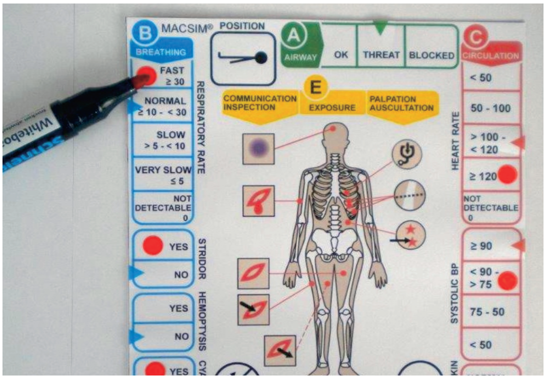

Figure 2. The physiological condition of the patient can - and should - be changed by the instructor using a whiteboard pen on the laminated card, based on the time passed since the injury, injury severity and the treatments performed/not performed.

5.1.4 Did the card give too much information?

The question can be addressed whether the casualty card gave too much, and too easily available, information compared with the "real" situation. If so, it would give a false (too high) accuracy and also a false (too low) consumption of time for primary evaluation of a patient.

However, the part of the card that was available for the responders gave far from a complete description of the injuries - it described only what the responder perceived when looking at, listening to and making a very rapid survey of the victim. As examples, the responder:

- Could register a penetration of the skin, maybe both an entrance- and exit hole, but had no information about injuries to underlying organs; It could be a harmless penetration [167,168] or it could be an immediately life-threatening injury requiring surgery within short time. Which alternative it was could only be found through repeated assessments of the patients' physiological condition, and/or by additional investigations in hospital (see below).
- Could register a hematoma on the skull, maybe combined with a slightly impaired response to talk, but had no information about a potential underlying brain injury; it could be a simple concussion or an expanding intracranial hematoma. Again - only repeated assessment and further investigations in hospital would reveal the true nature of the condition.
- Could register hematomas on the trunk after a blast, and maybe a loss of hearing, but had no information about the extension of blast injuries to lungs or visceral organs; it may take time until respiratory and circulatory impairment become apparent.

In summary, what the responder could read from the casualty card was the "surface" of the patient; decisions with regard to priority had to be based either on physiological criteria at the time of investigation or on "superficial" signs of injuries, calculating with potential risks related to those, in both cases requiring re-assessments.

Not until in hospital, more information could become available by information from the instructor, combined with X-ray and additional clinical and surgical findings.

5.1.5 Time for reading the card compared with the time to make a ”live survey”

Does it go faster to “read the card” than getting the same information from a rapid assessment of an injured patient? Pilot studies were made on that in connection to testing the simulation card on medical staff of different categories, using casualty-actors. For casualties with high GCS scores (= normal response to talk) no significant differences in time were found. For non-responsive patients, it took longer time to assess a “live“ casualty actor than the card, although the difference was not significant in this study. However, a more extended study on this may be needed. To secure not to get “falsely” shorter times for the cards than in reality we however added standard times for “live assessments” and registration both for prehospital and hospital settings.

5.1.6 The information in the cards

Each casualty card contained connected information available only for the instructor as illustrated in fig 2, Paper I. The definitive diagnosis for each patient, also serving as a base for the front side of the card available for trainees, was for the MRMI scenario based on the Madrid train bombings 2004 [25], with the same types and distribution of injuries as in this major incident. A number of burns as well as head-injuries of different severity was added from other scenarios in order to achieve a complete training in triage. The data with regard to within which times different interventions had to be performed to avoid preventable mortality and mortality were extrapolated from corresponding clinical material, since complete such data could not be extracted from the real incident. The reliability of such an extrapolation can of course be discussed. However, definition of “preventable mortality” was restricted to cases with apparent risk of mortality without rapid treatment, as for example:

- Patients suffering from blast lung injury with primary respiratory impairment (high respiratory rate, hemoptysis) not given oxygen and ventilatory support
- Patients with obvious signs of tension pneumothorax, including circulatory impairment, without decompression/thoracocentes prior to longer transports
- Intracranial or intra-abdominal bleeding with severe neurological or circulatory impairment and prolonged waiting times for surgery

These time limits, with relevance confirmed by expertise in traumatology, were standardized, and used for calculation of the outcome of the response with regard to potential preventable mortality and morbidity.

The standardized OR-times (=times required for surgical procedures) illustrated in fig 2, Paper I were only given to facilitate the use of the system for participants with limited experience of trauma-surgery. When the trainees were experienced surgeons (which became increasingly common with continuously more clinically experienced staff attending the courses) the trainees made decisions on surgical strategy based on the description of surgical findings (see below) and the instructors adjusted the times for surgery according to that.

The ISS was calculated for the overall severity and probability of survival for each patient. ISS, based on AIS (Abbreviated Injury Scale), is a classification of trauma severity during the acute phase [169].

As a development of the system, each casualty card was also linked to relevant, imaging procedures; Plain X-ray (lung- and skeletal), CT and USG. For all positive findings, X-ray pictures illustrating the findings were presented to the trainees on a computer screen as base for decision on further actions. These pictures were only in limited number real pictures from the Madrid scenario and the rest were pictures (with the same findings) from other scenarios or injuries, used with permission. For casualties undergoing surgery, the surgical findings (based on injury descriptions as in fig 2, Paper I) were illustrated with schematic drawings.

We have also tested the MACSIM system for training on different levels, from very basic as undergraduate training for medical- and nursing students (fig 3) to very advanced as training of surgeons in trauma- management in scientific meetings (fig 4). The evaluations from all such tests have so far been very positive and also helped to further develop the system.

Figure 3. Use of the MACSIM system for basic training of student nurses at the University of Örebro (Sweden). The simulation card is here in a larger size attached to casualty actors where the instructor can change the condition of the "patient" with movable clips.

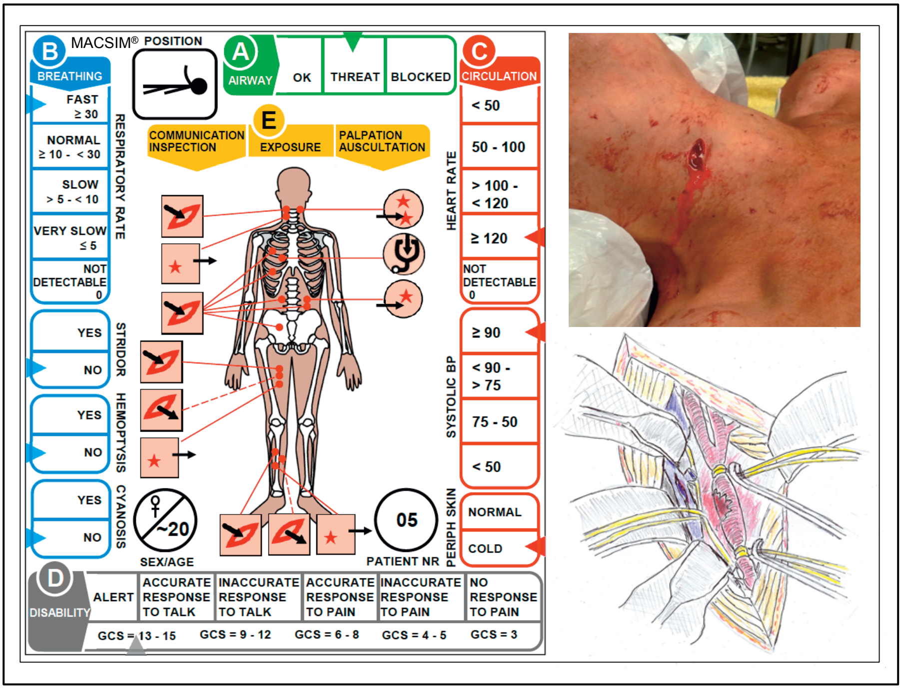

Figure 4. Use of the MACSIM system for advanced training of surgeons in a mentometer session at the European Congress of Trauma and Emergency Surgery (ECTES), Basel 2011 and during the Surgical week in Sweden in 2013. It has also been used for training in triage for paramedics at ECTES in Lyon 2013. This way of illustrating injuries with clinical findings, pictures of X-ray (when relevant) and surgical findings has been very appreciated and recognized as an efficient use of the patient bank in this system with all available data.

5.2 Use of the simulation model for comparison of different triage methods

5.2.1 Selection of triage to test the potential of the simulation system

As already referred to above, the triage in major incident response differs from the methodology in routine medical care. Since triage has a major impact on the outcome of the response, it is important that effort is devoted to develop and evaluate methods for this with optimal and documented efficiency. Reviews of available methods indicate that this so far not has been the case [83,100,107]. A variety of methods are used without any international consensus with regard to method.

Thus, it was natural to start by comparing the two principal methods of triage, anatomical and physiological - with each other. As model for physiological Triage Sort was selected, since this is the most commonly used method for secondary triage in the European countries, including Sweden.

5.2.2 Accuracy of the methodology

The same group of "patients" were presented to the test participants in two different ways by using two different models of the casualty card: One showing only the physiological parameters (with just a rudimentary description of the type of trauma), and one showing the type and distribution of injuries according to what a responder perceives at the first survey (Fig 4 a, b Paper I). The first model served as a base for Triage Sort, the second for anatomical triage.

One shortcoming could be a learning effect because the test participants started with physiological triage and then performed anatomical triage on the same patients. However:

- They did not see the character of the injuries when performing physiological triage,
- The order in which the cards were presented was changed, as well as sex and age of the patients

According to written and oral evaluations, test participants thought that they had triaged two different groups of patients.

The information on the casualty cards was, according to the evaluation by the test participants, sufficient to serve as a base for both anatomical and physiological triage. At preceding training with the cards illustrating other injuries, the test-persons learned the methodology very quickly.

The optimal triage category for each patient - with which the results of the test participants were compared - was here defined as the priority given by the expert group, based on complete information about the final diagnosis and clinical course for each injury, information that was not available for the test participants.

5.2.3 Outcome of the triage

Both anatomical triage and physiological triage according to Triage Sort reduced the preventable mortality compared to the level it potentially could have reached by sending these patients to hospital without any triage at all. On the other hand, the triage based on both these methods differed for all test groups from the optimal triage according to the definition above.

For Triage Sort, there were no significant intergroup differences, whereas for anatomical triage, the triage done by the most clinically experienced category (surgeons with trauma experience) differed significantly less from the "optimal" triage than the triage done by the other groups. This was valid also for the calculated outcome in preventable mortality (Figures 5 and 6, Paper I).

Since physiological triage automatically gives a level of priority based on criteria inserted in an algorithm, no or very small intergroup differences should be expected using this method. Still, differences were recorded, even if they not were significant. This could probably be explained by the fact that the method was just recently introduced in Sweden and the experience from using it in practice was limited. That the most clinically experienced group in fact had a somewhat larger diversion from the expert group can be explained by the fact that this group usually works on a level where anatomical triage is used - the majority of the group had never used, or previously been trained in, physiological triage.

5.2.4 Possible explanations for better results for anatomical triage for clinically experienced staff

One contributing factor to such a difference is that physiological triage does not take into consideration the potential course of the injury. A patient can have almost normal (and sometimes normal) physiological parameters immediately after the trauma, even with a potentially life-threatening injury [170]. For example, due to compensatory mechanisms, blood pressure in a young patient can for a while be kept on a normal, or almost normal, level even with a severe internal bleeding; an intra-abdominal bleeding can initially give very moderate symptoms and clinical findings. A person with clinical experience of severe injuries can include knowledge about the clinical course and potential risks in such injuries in the decision of priority.

Another factor contributing to this difference may be that physiological treatment not takes into account the potential effect of treatment. Very severe injuries, like severe burns or severe head injuries, may not be possible to save despite best possible treatment. In algorithms for Triage Sort for prehospital use, such patients will (according to the way Triage Sort is used in most parts of Europe) be classified as red-priority patients [86] whereas they with the use of anatomical triage can be triaged either as green or blue, depending on whether the special color for the "expectant" category has been nationally or locally adapted.

For anatomical triage, the priority can be set with consideration of the potential effect of treatment, "effect-related triage" [69,171]. Effect-related triage gives high priority to casualties where diagnostic and therapeutic measures have the greatest effect for maintenance of health and life. Vice versa, low priority is given to those where diagnostic and therapeutic measures have low effect.

A study on burn injuries from the propane-fire in Los Alfaques (Spain) 1978 [172,173] can serve as an example on "effect-related" triage. In fig 5, the two curves illustrate the mortality related to full thickness burned body area. The red curve shows the mortality rate for those who received immediate fluid resuscitation and the black curve those who did not receive any fluid resuscitation until of 24 hours after the injury. For a 40 % burn injury, the mortality for patients given immediate fluid resuscitation was between 5-10 %. The corresponding mortality for patients given delayed treatment was almost 90 %. This illustrated that immediate fluid resuscitation to patients with this extent of injury has a high effect on the outcome, and thereby should be given high priority [172].

On the other hand, fluid resuscitation in injuries with below 25 % or above 55 % burned area resulted in a very limited or no difference in outcome. In the first group because they could do for some time with no, or only oral, fluid supply, in the second group because of the bad prognosis regardless of treatment. These groups of patients could thus be given low priority for immediate fluid resuscitation [172]. These curves also look different for different groups of age [174,175].

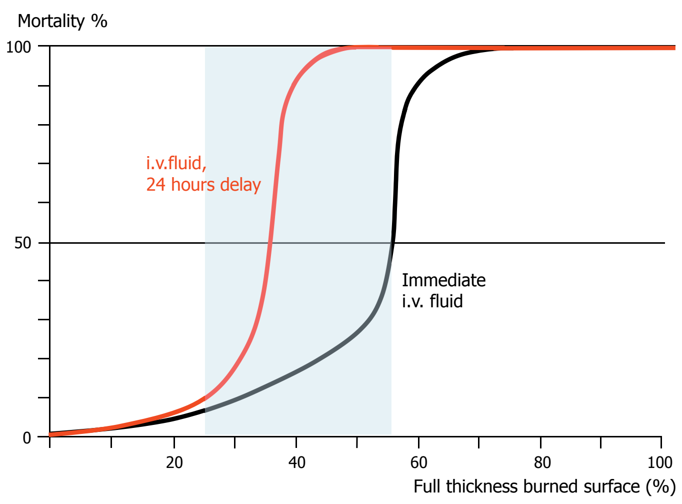

Figure 5. Illustration of the effects of early fluid treatment in burn injuries of different severities. After Arturson et al [173].

Based on clinical data, such "effect-graphs" can be made for most injuries [171] and used as a base for anatomical triage. This requires access to staff with clinical knowledge and experience.

5.2.5 Practical implications of the results

Presumed that the information gained from Paper I is relevant - which the collected data indicate - it may lead to the following interpretations with regard to clinical practice:

- Physiological triage according to Triage Sort
  - Gives a potential improvement of the outcome compared to no triage at all, but does not generate optimal priorities with regard to outcome for the triaged casualties
  - Gives equal results for staff with different levels of knowledge and experience

- Anatomical triage
  - Does not give better results than Triage Sort for staff with limited clinical experience of severe injuries, but
  - Gives better results than Triage Sort for more experienced staff

Since medical professionals of the latter category rarely are available in the early phase of the prehospital response to major incidents [176], physiological triage seems to be the method of choice on this level, as a simple method to learn and use.

However, to achieve a more efficient triage when there is access to more experienced staff, anatomical triage seems to be the method of choice.

With the current principles for major incident response in Sweden, access to this category of staff will mainly be limited to the hospital. Based on these results, it could be considered if deployment of more experienced staff to the scene in very extensive incidents with prolonged response time could be of benefit to achieve a more efficient triage.

Repeated studies with extended material, different scenarios and also including other methods for physiological triage are needed to give a more solid base for selection of methodology in triage in major incident response.

5.3 Use of the simulation model for interactive training in major incident response

Since it was developed 2009, this simulation system has been used for education and training in major incident response for many categories of staff on many different levels: Medical- and nursing students, postgraduate training of prehospital and hospital staff of different categories. The most advanced and complex training where it has been used so far is in the MRMI-courses and the evaluation of the accuracy of the system for training has in this project been focused on the use of the system in this course.

5.3.1 The MRMI-course

The MRMI-course was initiated by a group of international experts within the Section for Disaster & Military Surgery within the European Society for Trauma and Emergency Surgery 2009. The aim was to create an interactive course covering the whole chain of response to major incidents, which required a simulation system fulfilling a number of defined criteria. After evaluating different available simulation systems, the present system, which at that time just was developed for scientific studies on triage studies, was selected as the only one corresponding to all the listed demands.

Since the main part of this course was interactive, the simulation system was a key-component of the course, supplying the “bank” of casualty-cards with priority- and treatment tags, the symbols for all functions in the chain of response including staff of all categories, signs (in the early design) or pre-printed magnetic films (in the late design) for building up the scenario with prehospital-, transport- and hospital facilities and functions for command- and coordination (Fig 5, Paper II). Also, a pre-designed geographic are with description of resources and organization was supplied as a base for the standardized scenarios. Since the accuracy and validity of the course was to a major part depending on the simulation system, the evaluation of the system in this project also included an evaluation and validation of the course. This was done in two steps:

- Repeated evaluations during the phase of development of the course, proving a base for continuous adjustment and optimizing of the different components of the course (Paper II)
- Validation of the ability of the fully developed course to fulfill the given objectives for the training (Paper III)

5.3.2 Evaluations during the development phase

The development-process for this course was thoroughly described in Paper II, with the intention to be of benefit for others developing similar course-programs. The evaluations providing a base for this development included 470 participants from all parts of the world, 61 % with practical experiences from major incidents.

After the first pilot courses, with the aim to test and adjust the methodology, the evaluations were made in two steps:

- For the three first courses to focus on the accuracy of the simulation cards and quality of the simulation exercises
- For the next three courses to focus on how the different categories of trainees evaluated the effects of the training on specific competencies

The reasons to adjust focus for the evaluations during the study period were:

- The uniform evaluations from the first courses, provided by more than 140 experienced trainees of different categories, was considered sufficient to confirm the accuracy and quality of the simulation methodology from the trainees´ perspective
- Since the strategy had changed from mixed to more "pure" roles in either prehospital or hospital training, also influencing the recruitment of participants, it was considered important to separate the evaluations between these competencies, which was not done from the beginning
- It was also considered important to illustrate the trainees´ judgment of the effects of the training on specific prehospital and hospital fields of competence, and finally also of the accuracy of the course as a whole for training of major incident response for both these categories separately

As reported above, the accuracy of the simulation cards for this purpose was by 63 % of the trainees evaluated as "very good" and by 33 % as "good", the highest two out of six given alternatives. The accuracy of the course for training of major incident response was on a scale 1-5 by prehospital staff evaluated as 4.35 and by hospital staff 4.30. Altogether, this supported the accuracy of the simulation model for training in major incident response.

It also has to be taken in to consideration that these were average figures from a period of continuous improvements and that the course had not reached the fully developed form until the last of these courses. A continuous improvement of the evaluations could also be noted.

The more personal experience the trainees had, the more positive were they in their judgment of the course. This was a uniform observation by the faculty at the oral evaluations but could not be confirmed in the written evaluations since they were anonymous.

Figure 6 illustrates the broad distribution of participants in the MRMI-courses.

Figure 6. Introduction-slide from the MRMI-course in Stockholm 2013, illustrating the broad international distribution of participants. Trainees from 26 countries from all parts of the world have so far attended these courses, the majority with personal experience from major incidents. The faculty in the course above came from seven different countries: United Kingdom, United States, Israel, Italy, Croatia, Denmark and Sweden. All these courses have been based on the simulation system presented in this thesis.

5.3.3 Validation of the fully developed course

The increasing number of new simulation models in emergency preparedness and response presented in the literature, makes it important to secure that these models really increase the trainees´ ability to perform accurately in a major incident or disaster. Hsu et al [138,157] concluded that current evidence on the effectiveness of mass casualty incident training for hospital staff was limited, and that more attention had to be directed to evaluating the effectiveness of disaster training activities in a scientifically rigorous manner [138,157]. This is in accordance with other reviews on education and training in disaster medicine [70,177].

The limitations of traditional course-evaluations are that they are dependent on the trainees' opinions with regard to the knowledge and skills required for an accurate performance as the only indicator of the accuracy of the training. Therefore it is important to try to find more objective methods to validate the methodology of training.

The importance of not relying on one single test or method, but use multiple indicators and methods of assessment in the validation of educational programs, has been emphasized [178-180]. With this background, we evaluated different possible indicators on accuracy of the educational technique based on our simulation model.

In two of the MRMI-courses, tests of knowledge and skills were performed before and after the training session. This was made to see if it could theoretically be a way to illustrate an effect of the training. The test was a triage test performed immediately before and after the course. For the 105 trainees participating in that study, significant improvement of the result between pre-and post-course tests was registered for both methods. However, we were not able to find any method to completely exclude the training effects of just using the casualty cards and therefore we were by expertise in educational validation advised not to refer to this result as an indicator of the accuracy of the training.

Neither, we considered it possible to define how much of the registered intra-course improvements could be related to increased skills in using the simulation-methodology. We therefore did not use these observations as indicators on the accuracy of the training, even if they may support it.

When reviewing the literature, the most objective way to illustrate the accuracy of this training we have been able to identify is self-assessment of the trainees´ perceived knowledge and skills immediately before and immediately after the training. The importance that such assessments are being directly related to well defined and specific objectives for the training has been emphasized in the literature [178,181,182].

The accuracy of the used methodology for pre- and post-course self-assessments was confirmed by expertise on educational validation at the Faculty of Educational Research, University of Stockholm [183]. This method is considered to be the most objective way of confirming the accuracy of this kind of training as we have been able to identify.

We did not find any significant correlation between the level of pre-course assessed knowledge and the amount of improvement - a trainee with low pre-course ranking could show a limited improvement and one with high such ranking a high improvement, vice versa. The fact that the coordination group showed the highest improvement could not be explained by less qualification, this was generally a very experienced group. Our interpretation is that this particular way of training - in interactive sessions with opportunity to lead and coordinate an experienced group of trainees and get feedback - is a very efficient way to train this important group of leaders.

We consider the registered improvements related to the given objectives as an indicator of the accuracy of the training for the given purpose: Improvement of the trainees´ ability to fill their functions in a major incident response. Registered improvements in performance during the course may also support this conclusion, whereas limited conclusions can be drawn from formal course-evaluations or pre- and post- course tests.

5.4 Use of the simulation model for test of surge capacity and preparedness

5.4.1 Surge Capacity as a criterion of preparedness

As referred to in the introduction, one of the areas of Disaster Medicine that so far has been poorly developed is the methodology for quality assurance of preparedness for major incident response. This includes also definitions of criteria's for preparedness. One such criterion is "Surge Capacity", defined as "the ability to obtain adequate staff, supplies and equipment, structures and systems to provide sufficient care to meet immediate needs of an influx of patients following a large scale incident or disaster" [57].

It has been shown that hospital´s self-reported assessments of surge capacity are un-reliable [56], why there is a need of objective methods for this purpose. Most of the methods developed for assessing surge capacity deal only with one of the hospital components, usually the emergency department. However, the surge capacity is dependent on all components of the hospital and how they interact with each other. Live full-scale exercises with casualty actors are very expensive and resource-consuming if they should give sufficient information to evaluate the capacity of all these components. In summary, there has so far not been any standardized and widely accepted model available for determining the over-all surge capacity of a hospital.

In study IV, the simulation model described and evaluated in Papers I-III was used to test the surge capacity and preparedness of a major hospital. Using this model, covering the whole chain of response including management of individual casualties through all links of this chain, made it possible to illustrate the interaction between the different components of the response. This is important to get a true picture of the capacity of the hospital.

5.4.2 Defining the surge capacity of the hospital

The test illustrated the importance of including all the components with impact on the hospitals capacity to receive an unexpected heavy load of casualties. It illustrated the hazard in defining the surge capacity based only on single components of the chain of management. The capacity was first exceeded in the ED and the time when the inflow had to be stopped to avoid the risk to lose life and health could be defined (Fig 9, Paper IV). The capacity for surgery and intensive care was at that time far from exceeded, and if the inflow had been permanently stopped at this time, this important capacity had not been utilized. This test also illustrated that the overloading of the ED was temporary and it was possible after an interval to re-start receiving casualties. During that interval, it should have been necessary to refer severely injured patients to other hospitals.

Before the capacity of the ED again could have reached its limits, the lack of ventilators made it necessary to finally stop the inflow and this determined the final limit for the hospital´s capacity during this test. The capacity for surgery was at that time still not exceeded. If the hospital would have had access to a reserve supply of ventilators, the surge capacity could have been extended to the time when the surgical capacity was fully used.
These results showed that with the use of this model it was possible to illustrate

- How the different components in the chain of management interacted with each other
- That different components were limiting factors for surge capacity at different time intervals from the alert
- How measures to fully utilize the capacity of the hospital could be identified

5.4.3 Interpretation of the results

In a city with short distances to hospital and good access to transport resources, the inflow of casualties may start very fast and rise to high levels very quickly. At the Madrid bombings, from which this scenario was based, the nearest hospital received the first patients within minutes. In total, the hospital received 272 patients in 2.5 hours [25]. The test was done during office hours with all functions in the hospital fully staffed, but also all functions fully occupied with normal health care. If the test would have been done during non-office hours with only teams on duty available in the hospital, it would not have been possible to mobilize a similar number of resuscitation teams within the time period needed to cope with the rapid inflow of patients.

The hypothesis behind this study was that the tested hospital under these conditions should serve as the only receiving hospital for severely injured in a major incident, according to the model successfully used at the recent terror attack in the neighboring country, Norway [160]. The results illustrate that such a recommendation cannot be generalized. Even if this load of casualties was very high, it was based on a scenario that really had happened and thereby could happen again. This means that even if the excellent facilities of the large hospital should be utilized as much as possible, there must be a plan B to involve other hospitals when the capacity limit, even if temporarily, is exceeded.

It has to be emphasized that no general conclusion with regard to the surge capacity of a large hospital can be drawn from this test. What is presented in this study is a methodology based on a simulation system with a very high level of detail with regard to clinical data. This methodology can be used to test any hospital or unit within the health care system, but every such test has to be based on the specific conditions valid for the tested hospital, both with regard to capacity for all functions and with regard to organization and planning, methodology and experience/competence of involved staff, the latter achieved by letting the serving staff act in the test.

In addition, conclusions with regard to surge capacity of a hospital cannot be drawn from one single test. Maybe this should not be considered as a limitation of the study - it should rather be a general statement that defining surge capacity, regardless of method, requires more than one test, and tests both during office-hours and non-office hours.

5.4.4 Accuracy and potential of the simulation model for this purpose

The accuracy of the results from this test is of course dependent on the accuracy of the simulation system used for the test. This system is based on real scenarios, which validates that the casualty load and also the type and distribution of injuries is realistic.

The staff participating in the test, many with extensive clinical experience, evaluated this model as accurate for its purpose (Table 6, Paper IV). They also considered the test as an important and efficient training. The test also gave a good picture of the hospitals disaster plan and preparedness for major incidents and served as base for improvement and adjustments of the plan. In this way, the test also served as quality assurance of disaster preparedness, a field where disaster medicine so far has been far behind other areas in medicine.

Even if a simulation model like this includes involvement of staff, it is still much less expensive than a test with live casualty-actors brought into the hospital, and it can be done with minimal disturbance of the normal activity in the hospital. Once the hospital is set up, it can be preserved on magnetic film-sheets in rolls (described in Paper II), ready to re-set very quickly which creates continuous access to a system both for training, quality assurance and evaluation of modifications in the organization.

6 GENERAL CONCLUSIONS

- A simulation model was created and developed with the aim to be a tool for research, education and quality assurance in major incident response. In accordance with defined aims, the model appeared to be able to:
    - Supply information on a sufficient level of detail to provide a base for decisions on all levels of the chain of response
    - Illustrate the consequences of such decisions with regard to consumption of time and resources, efficiency of resource-utilization and result of the response
    - Give a measurable result of the response for the parameters above
    - Be used for illustration of scenarios with multiplicity and severity of injuries as in recent major incidents

- The model was tested and evaluated within the following fields of major incident response:
    - As a scientific tool by comparison of different triage methods in major incident response with regard to accuracy and efficiency
    - As an educational tool by development and validation of an interactive training program in major incident response for staff of all involved categories
    - As a tool for quality assurance by testing of capacity and preparedness of a major hospital in response to a simulated incident, based on a real scenario

- In all the studied areas, the model was by participating staff of all categories evaluated to be accurate for its purpose

- As a method for comparison of triage methods, it illustrated differences in accuracy and outcome between the two principal methods, anatomical and physiological triage, for different categories of staff with different levels of competence and experience, providing a base for discussion when and where to use the different methods.

- As a method for education and training, it provided the base for the start and development of an international training program, generating the establishment of seven international training centers in different countries based on this methodology

- Validation of the training program showed that it accurately fulfilled the specific objectives of the training which were based on experiences from recent major incidents

- As a method for testing capacity and preparedness, it could be used to identify the critical limiting factors for surge capacity in a major hospital and also illustrate how these factors interacted with each other and how different functions could be identified as limiting factors at different times during the response. It also provided a base for assessment of preparedness, organization and performance in major incident response.

7 FUTURE PERSPECTIVES

7.1 Computerization of the simulation system

This project started by developing a "manual" model by two reasons: (a) positive experiences from using manual models for interactive training and (b) the aim to have a manual model of the system fully developed and thoroughly tested before starting the time- and resource-consuming processing of the extensive amount of data into computer programs.

The project is now at the point where this model is developed and tested as a tool both for methodological development and evaluation, education and training and assessment of preparedness and performance in major incident response. Perhaps it is now time to apply for funding for computerization of the simulation system. The aim is not to design a "computer game" for individual training. Since coordination and communication between all participating agencies and staff of different categories is such an important component in major incident response, a training model for this purpose must include this component. Based on this, the aim will be to as a first step start to computerize specific components of the system, such as

- Triage and treatment of casualties based on the information included in, and connected to, the cards
- Transport logistics
- Processing of casualties in hospital units as emergency department, surgery and intensive care

and include these components in a test- and training system where different categories of staff work at computer screens within their areas of responsibility and on different levels in the chain of response, communicating with each other.

As a second step is planned a model covering the whole response and based on strictly standardized scenarios, where the result of single modifications in organization, resources of all kinds, performance or training can be measured by changes in the outcome of the response. Data required for this are already in the system and this development could give access to a useful tool both for planning and organization, methodological development, training and quality assurance.

7.2 Extending the model with additional scenarios

The simulation model has so far been focused on incidents caused by physical trauma, so far being responsible for the major parts of deaths caused by major incidents. However, additional scenarios based on this simulation system are already under development:

- A scenario with incidents caused by hazardous material is under testing at the Slovenian MRMI center
- A scenario based on missile injuries for military purpose has been tested by NATO with positive result and this scenario is under expansion
- A "bank" of burn injuries is already available for simulation of scenarios with large numbers of burns
- A specially adjusted model of the system was recently (March 2014) used for a simulated evacuation of a major hospital in Stockholm as a part of a national project financed through the Swedish National Board of Health and Welfare with the aim to provide a base for national guidelines for such evacuations (manuscript under publication).

7.3 Further development within the studied fields of Disaster Medicine

As concluded in Paper I, further studies are needed with the aim to reach a consensus with regard to the most efficient method(s) for triage for different levels of competence at different levels of the chain of response to major incidents. A methodology for this is now available and the casualty card creating the base for this can be used to test any available triage method.

The testing of the system for training has so far mostly been restricted to the use in the MRMI-courses, whereas the system already has been used for other courses for different levels of staff. The methodology in these areas has to be further developed and evaluated.

The development of the MRMI-course has so far led to the establishment of seven international MRMI centers in different countries, organizing national as well as international courses, and additional centers are planned. Building a network based on these centers for international exchange with regard to further methodological development and application to additional fields of Disaster Medicine is a great challenge. Further development of the simulation system, as being a key component in these courses, can be an important part of this.

Development of health care systems requires re-organizations and simulation tools can be an effective method to test future methodologies for prehospital response, especially with regard to command and communication. They might also be used for capacity tests when building new hospitals or re-building already existing hospitals.

Finally, the system has according to the results from this thesis a potential to be developed into a tool for methodological assessment and quality assurance in planning, preparedness, organization, performance and training. A computerized model of the system according to step 2 above can be a useful complement for this purpose.

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