Airway management in an anaesthesiologist-based pre-hospital emergency medical service

A study of safety of endotracheal intubation and feasibility of techniques relevant for entrapped patients and difficult airway management

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University of Oslo, Faculty of Medicine
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Preface 1

A talented young doctor with high ambitions for academic medicine lost his life while attempting to rescue gravely injured patients. Anders Rostrup Nakstad was strongly dedicated to research based medicine. Already as a medical student he performed scientific studies in acute medicine while working part time in the air ambulance service. Impressively, he was able to pursue his scientific work and finish a phd-thesis, while at the same specializing in anesthesiology. On behalf of the Faculty of Medicine, I express my deepest sympathy for his family, friends and colleagues.

Anders’ work to improve acute medicine and enhance healthy survival of patients stands out. An achievement I hope will help soothe the sorrow of those left behind.

Frode Vartdal
Dean
Preface 2

Two weeks prior to the day he planned to submit his thesis to the Faculty of Medicine at University of Oslo, Anders died when an ambulance helicopter crashed at Sollivågda January 14, 2014. I had already contacted Tom Silfvast, Hans-Morten Lossius and Signe Søvik and asked them if they were willing to evaluate his thesis if appointed by the Faculty of Medicine. Anders was very proud when all three immediately accepted the request. Fortunately, the Faculty of Medicine supported the idea that the committee should evaluate his thesis also after his death although a Ph.D. can not be awarded post mortem. Earlier this year, the committee informed the Faculty of Medicine that Anders’ thesis had a sufficient quality that under different circumstances the committee would have recommended that he would be allowed to defend his thesis in a public dissertation.

On his computer, we found the latest edition of his thesis and except for correction of some spelling errors and some layout changes, his thesis is exactly the way it was when we found it. No doubt, Anders would have made some final changes before submission but we have deliberately refrained from doing any changes that he may or may not have supported. Anders had very strong opinions on how he wanted to present his work.

As a medical student Anders started to work in the Akershus ambulance service because of his strong dedication to emergency medicine. It was in this period, Anders became aquainted with the Air ambulance department. He was unusually talented and had an impressive working capacity. Anders published his first paper in 2004, but the papers included in the this thesis have been published between 2009 and 2013. When Anders started with research he was a medical student, when he published his last papers he was a specialist in anaesthesiology and intensive care medicine and head of the Air ambulance department. An impressive career, indeed. Anders was very busy and he was never a full time Ph.D. student; all his research was done when he was either a full time medical student or a full time clinician. For that reason, he aimed at dr. philos-degree, instead of the more common Ph.D.-degree.

The preface is usually the last section that a Ph.D. student writes before submitting the thesis and Anders never wrote a preface. However, I have some ideas about what the preface would look like. I am certain that Anders would have mentioned colleagues, friends and family not mentioned here. I apologize for all omissions. I am responsible for the omissions, not Anders.
Anders would obviously have thanked Terje Strand and the Air Ambulance department for the opportunity to do research in the department. He would also have acknowledged the efforts of all his colleagues that provided him with clinical data and participated in the experimental studies that Anders ran. His coauthors (Terje Strand, Hans-Julius Heimdal and Per Bredmose) would have been especially mentioned for their efforts.

Anders was dedicated to his research, his clinical and administrative responsibilities, and he was very conscientious about how he spent his time. As far as I know, only once he attended an international congress even though he had many opportunities to travel abroad. Anders never prioritized such activities, and the reason was obvious; his wife, Elin, and their two young sons, Erik and Elias. Nothing was more important to Anders and he would without a doubt have thanked his family and dedicated the thesis to them. His hope was to spend more time with his family as soon as he had finished with his thesis. Furthermore, Anders would have thanked his twin brother – Espen and Anders were unusually close – and his parents and sister.

I was the unofficial supervisor of Anders’ – dr. philos-candidates are supposed not to have an official supervisor – and I am very greatful for having had the chance to get to know Anders as a researcher. We had planned to continue the research collaboration for years to come, but unfortunately that dream never became a reality.

Oslo, September 15, 2015

Mårten Sandberg
Airway management in an anaesthesiologist-based pre-hospital emergency medical service

A study of safety of endotracheal intubation and feasibility of techniques relevant for entrapped patients and difficult airway management

Cand. med. Anders Rostrup Nakstad
Air Ambulance Department Oslo University Hospital

Evaluation

The author has studied the safety of pre-hospital advanced airway management performed by anaesthesiologists, with a special focus on safety and difficult airway management. Through five scientific studies, the candidate explores six issues central to a better understanding of the challenges and a further development of pre-hospital advanced airway management.

The aims of the thesis are:

1. To investigate how close to the patient the helicopter emergency medical service (HEMS) is able to land in trauma missions, and to calculate on-scene-time (OST) in trauma missions and to what extent the need to perform an RSI intubation influences the OST.
2. To establish the frequency of oxygen desaturation, the success rate, and the use of adjuvant clinical tools during RSI endotracheal intubation performed in the field.
3. To evaluate the feasibility of video laryngoscopy in simulated scenarios of entrapped patients.
4. To compare the time consumption during endotracheal intubation to the use of two different supraglottic airway devices in simulated advanced airway management, including simulated entrapment of the patient.
5. To evaluate to what extent there is a training effect among anaesthesiologists when the same airway simulator is used repeatedly for evaluation of airway management techniques.
6. To evaluate whether there is a difference in performance at baseline level and after training with percutaneous and surgical techniques for cricothyrotomy in a cadaveric porcine airway model.

The studies are well performed and the results precisely reported. The author uses a relevant spectre of methods and demonstrates a good understanding of both the strong sides and the limitations of the methods used. His findings are thoroughly discussed with a germane use of references.

The five studies are all put into a whole in the thesis. The author gives a comprehensive overview of the history and present of pre-hospital anaesthesiologist-staffed emergency medical services and advanced airway management. He demonstrates a good overview of the present evidence base. Challenges and knowledge gaps are described. Through a clear presentation, his findings are fitted into the present knowledge on advanced pre-hospital airway management, and the contributions of his studies are well discussed.

Overall, the evaluation committee concludes that the submitted work by Anders Rostrup Nakstad fulfils the requirements for the Dr. Philos. degree.

Oslo, April 8th 2015

Hans Morten Lossius
Professor
University of Stavanger

Tom Silvfast
Professor
University of Helsinki

Signe Søvik
Associate Professor
University of Oslo
# Table of contents

**ABBREVIATIONS**  
9

**LIST OF PAPERS**  
11

**PART I – GENERAL INTRODUCTION**  
12

1.1 Historical background and present structure of the Norwegian emergency medical service (EMS)  
12

1.2 Airway management in anaesthesiologist based EMS  
23

1.3 SADs and video laryngoscopes  
33

**PART II – INTRODUCTION TO KEY ISSUES IN AIRWAY MANAGEMENT PROVIDED BY ANAESTHESIOLOGIST BASED PRE-HOSPITAL EMERGENCY MEDICAL SERVICES**  
39

2.1 On scene time (OST) and tactical aspects  
39

2.2 Pre-hospital ETI  
40

2.3 Airway management in entrapped patient  
41

2.4 Training effect of using fixed airway simulators and manikins in basic SAD training  
42

2.5 Pre-hospital cricothyrotomy  
43

**PART III - AIMS OF THE THESIS**  
44

3.1 Introduction  
44

3.2 The main aims  
44

**PART IV - MATERIAL AND METHODS**  
45

4.1 Paper I – Prospective observational study  
45

4.2 Paper II – Prospective observational study  
45

4.3 Paper III – Simulation study with use of one airway simulator  
46

4.4 Paper IV – Simulation study with use of two different airway simulators  
46

4.5 Paper V – Prospective, randomized, crossover simulation based trial  
47

4.6 Statistical analysis  
47

**PART V - SUMMARY OF RESULTS**  
49

5.1 Paper I  
49

5.2 Paper II  
49

5.3 Paper III  
50

5.4 Paper IV  
50

5.5 Paper V  
51
### PART VI – DISCUSSION

6.1 PAPER I - On scene time (OST) in HEMS trauma missions and how need to perform RSI intubation influences the OST 52

6.2 PAPER II - The establishment of the frequency of desaturation, success rate and use of adjuvant clinical tools when performing rapid sequence intubation in the field 54

6.3 PAPER III - Feasibility of video laryngoscopy in simulated entrapped patient scenarios 56

6.4 PAPER IV - The comparison of ETI, I-gel™ and LTS-2 in simulated advanced airway management and in simulated entrapment of the patient. 58

6.5 PAPER V - The difference in performance at baseline level and after training with percutaneous and surgical techniques for cricothyrotomy in a cadaveric porcine airway model 59

### PART VII – CONCLUSIONS

7.1 On scene time in HEMS trauma missions 61

7.2 Incidence of desaturation 61

7.3 Feasability of video laryngoscopes 61

7.4 Comparison of Macintosh laryngoscope, I-gel™ and LTS-2 61

7.5 Training effect in manikin studies 62

7.6 Difference between BACT and PCK 62

ERRATA 63

REFERENCES 64

REPRINTS OF PAPER I - V 73
## Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>ALS</td>
<td>Advanced life support</td>
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<tr>
<td>AMOHCA</td>
<td>Airway management in out-of-hospital cardiac arrest</td>
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<td>APLS</td>
<td>Advanced paediatric life support</td>
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<tr>
<td>AS-GEMS</td>
<td>Anaesthesiologist staffed ground based emergency medical service</td>
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<tr>
<td>ASA</td>
<td>American Society of Anesthesiology</td>
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<tr>
<td>ATLS</td>
<td>Advanced trauma life support</td>
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<td>BACT</td>
<td>Bougie assisted cricothyreotomy</td>
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<td>BLS</td>
<td>Basic life support</td>
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<tr>
<td>BVM</td>
<td>Bag-valve-mask</td>
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<tr>
<td>CICV</td>
<td>Can not intubate - Can not ventilate</td>
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<tr>
<td>CPR</td>
<td>Cardiopulmonary resuscitation</td>
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<tr>
<td>DAS</td>
<td>Difficult airway society</td>
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<tr>
<td>ECG</td>
<td>Electrocardiogram</td>
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<td>ECMO</td>
<td>Extracorporeal membrane oxygenation</td>
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<tr>
<td>ED</td>
<td>Emergency department</td>
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<td>EMS</td>
<td>Emergency medical service</td>
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<td>EMT</td>
<td>Emergency medicine technician</td>
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<tr>
<td>ER</td>
<td>Emergency room</td>
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<tr>
<td>ERC</td>
<td>European resuscitation council</td>
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<tr>
<td>ET</td>
<td>Endotracheal tube</td>
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<td>ETCO₂</td>
<td>End tidal carbon dioxide concentration</td>
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<td>ETI</td>
<td>Endotracheal intubation</td>
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<td>FW</td>
<td>Fixed wing</td>
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<td>GCS</td>
<td>Glasgow coma scale/score</td>
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<td>GEMS</td>
<td>Ground based emergency medical service</td>
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<td>GPS</td>
<td>Global positioning system</td>
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<tr>
<td>Acronym</td>
<td>Full Form</td>
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<td>HEMS</td>
<td>Helicopter emergency medical service</td>
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<tr>
<td>IABP</td>
<td>Intra aortic balloon pump</td>
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<tr>
<td>ILMA</td>
<td>Intubating laryngeal mask airway</td>
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<tr>
<td>IQR</td>
<td>Inter-quartile range</td>
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<tr>
<td>ISS</td>
<td>Injury severity score</td>
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<tr>
<td>LMA</td>
<td>Laryngeal mask airway</td>
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<tr>
<td>LT-2</td>
<td>Laryngeal tube (no. 2)</td>
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<td>LT-S</td>
<td>Laryngeal tube with suction</td>
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<tr>
<td>MASH</td>
<td>Mobile army surgical hospitals</td>
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<td>MEMS</td>
<td>Military emergency medical system</td>
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<td>MODS</td>
<td>Multi organ dysfunction syndrome</td>
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<tr>
<td>NFT</td>
<td>No flow time</td>
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<tr>
<td>NO</td>
<td>Nitric monoxide</td>
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<td>OHCA</td>
<td>Out of hospital cardiac arrest</td>
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<td>OR</td>
<td>Operating room</td>
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<tr>
<td>OST</td>
<td>On scene time</td>
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<tr>
<td>PCK</td>
<td>Portex cricothyreotomy kit</td>
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<tr>
<td>RFST</td>
<td>Rapid for step technique</td>
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<tr>
<td>RNOAF</td>
<td>Royal Norwegian Air Force</td>
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<tr>
<td>RRC</td>
<td>Rapid response car</td>
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<tr>
<td>RSI</td>
<td>Rapid sequence intubation</td>
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<td>SAD</td>
<td>Supraglottic airway device</td>
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<tr>
<td>SAR</td>
<td>Search and rescue</td>
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<td>SBP</td>
<td>Systolic blood pressure</td>
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<tr>
<td>SD</td>
<td>Standard deviation</td>
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<tr>
<td>SpO₂</td>
<td>Oxygen saturation</td>
</tr>
<tr>
<td>SSAI</td>
<td>Scandinavian Society of Anaesthesiology and Intensive Care Medicine</td>
</tr>
<tr>
<td>TBI</td>
<td>Traumatic brain injury</td>
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<tr>
<td>VL</td>
<td>Video laryngoscopy</td>
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List of Papers


Part I – General Introduction

1.1 Historical background and present structure of the Norwegian emergency medical service (EMS)

1.1.1 Scandinavian anaesthesiology pioneers and their importance for EMS development in Norway

Norwegian EMS has developed based on the substantial work of past clinicians and scientists. The recurring polio epidemics that hampered parts of the world during the 20th century were enormous challenges to the health care systems. With John Haven “Jack” Emerson’s invention of the iron lung in 1931, the first efficient, economical tool for vital organ support slowly became a reality. Emerson called his invention the “Respirator” (figure 1) [1]. Such negative pressure based ventilation assistance devices were large, static and expensive, but for more than two decades they were the only hope for young patients suffering from bulbar paralysis due to polio infection.

Figure 1: Jack Emerson’s “Respirator” (picture from the Oslo University Hospital Museum)

The last pandemic lasted from 1950-54. In 1962 a massive vaccination work was started in Oslo based on the work of Jonas Salk and Albert Sabin.
In 1952 Denmark was struck by an especially severe wave of the polio pandemic. With the development of the positive pressure ventilation strategy and the dedication to use it at a massive scale, Danish anaesthesiologist Bjørn Ibsen and epidemiologist Mogens Bjørneboe improved the survival of young victims of the bulbar polio infection [2, 3]. These efforts may be referred to as the first examples of advanced life support (ALS) and were the basis for further development of the areas of anaesthesiology and intensive care medicine. Scandinavian anaesthesiologists continued with contributions in the development of a modern health care service from the early 1950s [4]. Parallel to the development of fundamental techniques for in-hospital anaesthesia and intensive care medicine, an increased attention was made to the pre-hospital phase of patient care. Based on modern cardiopulmonary resuscitation (CPR) developed by Peter Safar, William Kouwenhoven and James Jude [5-8] the Norwegian anaesthesiologist Bjørn Lind and business developer Aasmund Lærdal introduced the principles and teaching of modern CPR in the health care services [9, 10]. Anaesthesiologists Ivar Lund and Andreas Skulberg contributed in introducing early CPR performed by lay-persons [11]. Skulberg paid special attention to the importance of the medical quality of the ambulance service and founded the first health care education program for ambulance drivers in Norway that has continued since the early 1970s [12, 13]. Together with Jens Moe and colleagues in the Oslo Ambulance Service he also saw the potential in a specially designed physician-manned ambulance in Norway (figure 2). The first of its kind went into service in 1967 [14] and has been

Figure 2: The physician manned ambulance in Oslo, 1967
The vehicle was manned with two ambulance-drivers, one physician and in some periods with an anaesthetic nurse. Jens Moe to the left
operative as a platform for education, research and anaesthesiologist based EMS ever since. On September 2nd 2013, the service was extended to a full scale 24/7/365 activity including intensive care transport capabilities.

1.1.2 The development of a modern helicopter EMS

Jens Moe devoted a major part of his life to the development of modern EMS, and he played a vital role in the development of a helicopter EMS (HEMS) in Norway. His inspiration was the world’s first permanent civil air ambulance helicopter at base “Christoph I”. It entered service in Munich, Germany on November 1th, 1970. Light helicopters had previously been introduced to the military EMS (MEMS) during the Korean and Vietnam wars where they were used to retrieve soldiers from the battlefield to the Mobile Army Surgical Hospitals (MASH) [15]. A BO 105 helicopter could travel with a speed of more than 210 km/h and follow a direct track. Moe understood that this was especially useful in Norway, and that it would be possible to rapidly reach patients even in remote areas. The helicopter could carry a specially trained team providing the same treatment as would be offered in the emergency room (ER) of a hospital. HEMS would also make it possible to transport trauma patients directly to specialized treatment facilities and thus reduce time to definitive care.

Moe was not able to make the government fund the start of the air ambulance service. Instead, he joined efforts with colleagues from the ambulance service in Oslo and started the Bård Østgaard’s Foundation, later renamed Norwegian Air Ambulance Foundation, that rapidly gained strong support from the public. With the help from some key leaders of the central hospital in Akershus County they were able to start the first HEMS operations in the autumn of 1978 (figure 3). With the strong support of members, local politicians and the public the Norwegian Air Ambulance Foundation introduced HEMS to Stavanger, Trondheim and Bergen within the first ten years.

![Figure 3: The first HEMS mission in Norway, June 2nd, 1978](image)

*The BO-105 is taking off from Akershus Central Hospital (SiA) to respond to a traffic accident*
In 1988, the government accepted HEMS as a formal part of modern health care and secured the founding of a national air ambulance system (figure 4). Bases were established in Tromsø, Brønnøysund, Trondheim, Bergen, Stavanger, Lørenskog and Dombås. The national air ambulance service was lead by the Minister of Social Affairs. Aircraft operators contracted with The National Insurance Administration (Norwegian: Rikstrygdeverket) to provide dedicated emergency care with specially equipped ambulance airplanes and helicopters.

New bases were added to provide the majority of the population with the service. Supported by the Norwegian Air Ambulance Foundation and the National Air Ambulance Service further improvements in flight safety, GPS-based navigation systems, electro medical equipment and aircraft performance have helped widen the availability of the service. With the exception of one base, all Norwegian HEMS crews at present consist of a pilot, a HEMS rescue paramedic and a HEMS anaesthesiologist. The HEMS rescue paramedics have a professional background as paramedics or nurses and they undergo a rigorous selection process. In addition they receive supplemental medical training. The anaesthesiologists usually spend approximately 50-80 % of their working hours in the pre-hospital service and the remaining time in-hospital as consultants in anaesthesia and intensive care medicine.

Figure 4: Loading of patient from ambulance, 2010

Picture taken on the helipad in Drøbak. The helipad was built due to the efforts of Lasse Hermansen and co-workers
1.1.3 The development of a modern fixed wing (FW) air medical service in Norway

Air ambulance patient transport was carried out in a small scale in the 1930s with the first known in 1932. After 1945, small civilian seaplanes were utilized in the western and northern parts of Norway. In 1948, a total of 300 patient transports were made including approximately 100 missions performed by military aircrafts. The Royal Norwegian Air Force (RNOAF) added air ambulance capacity and range with their Catalina-aircrafts for several years. From the 1950s to 1984, five commercial airline companies (Mørefly, West-Wing, Trønderfly, Firdafly and Norving) were engaged by the authorities in order to maintain a FW air ambulance service.

During the 80s and 90s the FW air ambulance service also gradually expanded. With the opening of the new national airport at Oslo Gardermoen in 1998, another base was added to a total of seven bases using nine Beech King 200 aircrafts. The service is dominated by secondary retrievals and tertiary transfers. In the northern parts of Norway, however, primary missions are numerous (figure 5).

1.1.4 The development of search and rescue (SAR) helicopters and their role as an integrated part of the national air ambulance service

The SAR helicopters of the RNOAF 330 sqad started their operations in 1973 primarily as a SAR unit for off-shore services (figure 6). When new bases were established in the north and west, the squadron became important providers of EMS in rural parts of Norway. In 2008, the SAR helicopters were upgraded with electro medical equipment and it became mandatory that the physician on board should be a consultant anaesthesiologist, making the SAR helicopters an equal component of the National Air Ambulance Service. The number of SAR bases increased in 2008 (Rygge) and 2010 (Florø) to a total of six bases providing emergency medicine. SAR crews consist of six persons; two pilots, one navigator, one engineer, one SAR rescue paramedic and one anaesthesiologist. The HEMS rescue paramedics have professional background as ground ambulance paramedics or nurses and undergo a thorough selection process. In addition, they receive supplemental medical and rescue technique training. The medical volume in the SAR service is lower than in civilian HEMS, but is
compensated with the anaesthesiologists spending approximately 50-80 % of their working hours in hospitals as consultants in anaesthesia and intensive care medicine.

1.1.5 The role of rapid response cars (RRCs)

In addition to the aircrafts, HEMS and SAR bases are equipped with rapid RRCs that are used by the crew when suitable (figure 7). The Norwegian Air Ambulance Foundation has made large contributions securing that all twelve HEMS-crews and six SAR-crews have specially equipped RRCs available. The vehicles are important as alternatives to the helicopters in cases of bad weather or when the patient is situated close to the helicopter base location [16]. In contrast to many other nations, the crew performing ground EMS (GEMS)-missions in Norway are identical to the crews performing HEMS missions.

1.1.6 RRCs providing GEMS without HEMS-crew

The two GEMS bases located in Oslo city and Haugesund city are run by two-person crews comparable to a HEMS crew utilizing the RRC: one paramedic and one anaesthesiologist (figure 8).
These are very similar to the composition of the anaesthesiologist staffed ground based EMS (AS-GEMS) vehicles in Denmark and Sweden. The Oslo GEMS is part of the same medical quality system and organization as the Oslo HEMS base.

1.1.7 Present structure of the National Air Ambulance Service

Figure 9: Location of HEMS, SAR and FW bases in Norway, 2013
After the 2002 hospital reform the responsibility for air ambulance services was transferred to the Regional Health Authorities (Norwegian: Regionale Helseforetak). In 2004 they established a joint subsidiary, National Air Ambulance Services of Norway. The administration is located in Bodø. It is responsible for contracting operators to the bases. The operators provide pilots and HEMS paramedics while the local health trusts provide the anaesthesiologists. The geographical base structure of rotor wing air ambulances, SAR helicopters and FW air ambulance planes in Norway is illustrated in figure 9.

1.1.8 The air ambulance department of Oslo University Hospital

The research projects that are presented in this thesis were performed at the Air Ambulance Department of Oslo University Hospital. This department has the medical responsibility for the HEMS helicopter anaesthesiologists at Oslo/Lørenskog, the air ambulance aircrafts nurses at Oslo/Gardermoen, the anaesthesiologists at SAR base Rygge, the anaesthesiologists at the physician manned ambulance in Oslo and the nurses and anaesthesiologists in the Intensive care ambulance. The department also coordinates specialized intensive care transports with use of intra aortic balloon pumps (IABP), nitrous monoxide (NO) and extra corporal membrane oxygenation devices (ECMO). ECMO-facilitated transports are made in cooperation with the ECMO-team of the Oslo University Hospital Rikshospitalet (figure 10). The 335 squadron of the RNOAF provides air transport of the specially designed intensive care ambulance when that modality is most suitable.

Figure 10: Static display of the ECMO-transport concept, 1998
1.1.9 Educational level and in-hospital training in present HEMS/GEMS

All Norwegian HEMS and SAR bases comply with the national standards for rescue paramedics and air ambulance anaesthesiologists. Advanced trauma life support (ATLS) and advanced paediatric life support (APLS) courses and a variety of national courses are regarded as obligatory. In recent years increasing demands have been placed on the HEMS anaesthesiologist making in-hospital training in neonatal intensive care departments compulsory.

Most Norwegian pre-hospital anaesthesiologists work regularly as in-hospital anaesthesiology consultants. The importance of regular in-hospital training to maintain adequate skills is underlined by the findings of Sollid et al. [17]. In their study 88% of HEMS anaesthesiologists reported that their number of pre-hospital intubations was not sufficient to maintain proficiency and that additional training was necessary.

1.1.10 Similarities and differences between the Nordic countries

A review of similarities and differences between the Nordic HEMS/GEMS was published by Langhelle et al. in 2004 [18]. Even though the use of vehicles and their geographical challenges vary, the pre-hospital services in Scandinavia have several similarities. Consultant anaesthesiologists are widely employed and provide advanced emergency care as well as on site support for paramedics in the ambulance service. In a recent population-based, prospective study published by Krüger et al. the activity in 16 anaesthesiologist-staffed pre-hospital services in Denmark, Finland, Norway and Sweden was recorded. Based on the fact that the services studied cover half of the Scandinavian population the incidence of critical illness and injury was calculated to be 25-30 per 10,000 inhabitants per year [19]. The HEMS/GEMS services in Scandinavia are becoming more equal with time as both Sweden and Denmark have increased the number of bases in recent years (table 1 and figures 11 and 12).

<table>
<thead>
<tr>
<th>HEMS</th>
<th>Norway</th>
<th>Sweden</th>
<th>Denmark</th>
<th>Finland</th>
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<tr>
<td>GEMS</td>
<td>12</td>
<td>5?</td>
<td>14?</td>
<td>6</td>
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<td>FW</td>
<td>2</td>
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<td>SAR</td>
<td>7</td>
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In a recent study the organization and education of pre-hospital anaesthesiologists in Scandinavia were found to be basically identical [20]. The medical work includes a variety of patient groups and rests on the basis of the specialty of anaesthesiology. Diagnostic skills and extensive knowledge of EMS operative logistics, intensive care medicine and pre-hospital trauma management were highlighted as important factors.
1.1.11 Medical effects of HEMS and GEMS

It is likely that the potential beneficial effects of HEMS and GEMS are due to time efficient response and transport as well as the quality of diagnostics and treatment on site and en route [21, 22]. Parts of the literature, however, do not discriminate between different aircrafts, dispatch criteria and medical crew compositions of different HEMS in the world. While American HEMS use flight nurses or paramedics, most HEMS in Australia, Japan and Europe are based on emergency physicians or anaesthesiologists. HEMS may be used for primary and secondary retrieval and for medical and trauma patients. It is imperative to acknowledge the large changes in hospital structure, demographics and medical treatment during the last twenty years. The literature from past decades must be read with these differences in mind. Recently Krüger et al. developed an Utstein-style template for uniform documentation of core data describing physician based EMSs in Europe [23].

1.1.11.1 Early studies of different components of the Norwegian air ambulance service

HEMS transport of sick neonates in central Norway during the 14-year period 1988-2001 was studied by Berge et al. [24]. The study concluded that HEMS at that time provided rapid medical assistance in a wide spectrum of neonatal problems, but more attention should be paid to proper ventilation and prevention of hypothermia and hypoglycaemia. Hotvedt et al. evaluated the HEMS base in Tromsø in the period 1989-1990. They concluded that HEMS can provide considerable health benefits for selected patients in the rural setting [25]. In a study on the SAR based HEMS in northern Norway by
Waage-Nielsen et al. in 2002 a large proportion of missions with nonlife-threatening cases were reported from the period 1988-1999 [26]. These studies are all based on data from the 1980s and 1990s, a time when the qualifications of the physicians were variable and the large changes in the hospital structure had yet to be implemented.

Both FW air ambulances and HEMS are important tools to compensate for the demographic and geographic differences in Norway. Despite this, there is a lack of publications in context to the ongoing development of hospital systems and treatment.

1.1.11.2 Systematic reviews
An American meta-analysis published in 2006 found that a large proportion of patients transported from the scene by helicopter had nonlife-threatening injuries [27]. This is in contrast to recent studies from the European HEMS systems where the physician-based HEMS is more frequently deployed to patients with severe injury [28]. A retrospective cohort study published in 2007 involving 223,475 major trauma patients, transport by helicopter compared with ground services was associated with improved survival to hospital discharge [29]. A recent Cochrane systematic review on effects in trauma patients concluded that an accurate composite estimate of the benefit of HEMS could not be determined. This was reported to be the result of the methodological weakness of the available literature. Five of the nine multivariate regression studies indicated improved survival associated with HEMS [30]. All kinds of HEMS were included in the review.

1.1.11.3 Recent studies on Scandinavian and German HEMS
Lossius et al. demonstrated life years gained in every 14th patient assisted by a Norwegian anaesthesiologist manned pre-hospital EMS (HEMS Stavanger). The role of the anaesthesiologist was crucial for health benefits and the effect was identical for HEMS and GEMS missions performed with the same medical crew [31]. Knudsen et al. have demonstrated earlier reperfusion of patients with ST elevation myocardial infarction when comparing HEMS and traditional EMS in a region of Denmark [32]. Hessefeldt et al. reported that implementation of HEMS in the eastern parts of Denmark was associated with significant reduction in time to the trauma centre for severely injured patients. They also found a significant reduction in secondary transfers of trauma patients from 50 % to 34 %. Furthermore, a reduction in 30-day mortality in the regional trauma centre was reported [33]. In a large retrospective study based on 13,220 German trauma registry patients, HEMS patients were found to be more seriously injured and had significantly higher incidence of multi organ dysfunction syndrome (MODS) and sepsis than patients retrieved by local GEMS. Despite the differences the HEMS demonstrated a survival benefit compared to GEMS [34]. In a Dutch study a similar pattern of patients with traumatic brain injury (TBI) was found [28]. In a European expert panel process five top priority research fields of modern HEMS were identified [35]:

1) Appropriate staffing and training in pre-hospital critical care and the effect on outcomes
2) Advanced airway management in pre-hospital care
3) Definition of time windows for key critical interventions which are indicated in the pre-hospital phase of care,
4) The role of pre-hospital ultrasound
5) Dispatch criteria for pre-hospital critical care services.

The studies in this thesis are linked to topic 1, 2 and 5 in this list.

1.1.12 Core ALS elements provided by modern HEMS/GEMS

The literature on basic and advanced life support (BLS and ALS, respectively) effects is dominated by retrospective observational studies from systems that are very different. In a systematic review by Ryynanen et al. effectiveness of pre-hospital ALS was found in patients suffering from myocardial infarction, and some studies demonstrate effects in patients suffering from severe TBI and multiple trauma [36]. Based on the published literature BLS seems adequate for victims of penetrating trauma and very short time to hospital. In another systematic review with fewer articles included, ALS was judged beneficial in patients with cardiac arrest, especially when it was provided by physicians. The authors of both reviews underscore that only few controlled pre-hospital ALS studies of sufficient quality and strength exist.

One major problem with the studies on pre-hospital ALS and BLS is that they focus on how often certain ALS procedures are performed without controlling the indications for and the quality of the performance. The diagnostic quality and the quality of the ALS provided would most likely be of great importance. For instance, endotracheal intubation (ETI) of TBI patients may be harmful when performed by inexperienced personell, while the same procedure may be beneficial if performed with perfection. The continued quality of target-controlled changes in advanced treatment is important. Pre-hospital ventilation is for instance associated with lower mortality after severe TBI [37].

Thus a list of core elements in the ALS provided by European HEMS/GEMS must include all aspects of the ALS provided in the areas of anaesthesiology and intensive care medicine (table 2).

<table>
<thead>
<tr>
<th>Table 2: Core elements in ALS provided by HEMS/GEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Clinical diagnostic skills and detailed knowledge on definitive treatment options</td>
</tr>
<tr>
<td>2. Advanced airway management skills</td>
</tr>
<tr>
<td>3. Anaesthesia and vital organ support (vasoactive infusions)</td>
</tr>
<tr>
<td>4. Basic surgical interventions (thoracic drainage)</td>
</tr>
<tr>
<td>5. Continuous intensive care treatment, including neonatal intensive care</td>
</tr>
</tbody>
</table>

1.2 Airway management in anaesthesiologist based EMS

1.2.1 Methodical challenges in studies of pre-hospital advanced airway management

There is much literature on advanced airway management and pre-hospital airway management. Thus some criteria must be set for what kind of literature is relevant to answer questions on the
specific parts of airway management in anaesthesiologist based pre-hospital EMS. In the work with this thesis, the following criteria were used to identify relevant literature.

**Table 3: Criteria for detecting literature of relevance**

<table>
<thead>
<tr>
<th>Educational level</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Pre-hospital anaesthesiologists</td>
<td></td>
</tr>
<tr>
<td>2. Pre-hospital emergency physicians</td>
<td></td>
</tr>
<tr>
<td>3. Pre-hospital physicians (non-consultants in emergency medicine or anaesthesiology)</td>
<td></td>
</tr>
<tr>
<td>4. Pre-hospital anaesthetic or intensive care nurses</td>
<td></td>
</tr>
<tr>
<td>5. Paramedics</td>
<td></td>
</tr>
<tr>
<td>6. Emergency medicine technicians (EMTs)</td>
<td></td>
</tr>
<tr>
<td>7. Unskilled providers</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Population</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Trauma patients and medical patients</td>
<td></td>
</tr>
<tr>
<td>2. Trauma patients only</td>
<td></td>
</tr>
<tr>
<td>3. Medical patients only</td>
<td></td>
</tr>
<tr>
<td>4. Patients suffering from cardiac arrest</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Environment</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Pre-hospital</td>
<td></td>
</tr>
<tr>
<td>2. Simulated pre-hospital</td>
<td></td>
</tr>
<tr>
<td>3. In-hospital emergency room (ER)</td>
<td></td>
</tr>
<tr>
<td>4. In-hospital operating room (OR)</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Emergency patient pre-hospitally</td>
<td></td>
</tr>
<tr>
<td>2. Emergency patients in the emergency department (ED)</td>
<td></td>
</tr>
<tr>
<td>3. Elective patients in the operating room</td>
<td></td>
</tr>
<tr>
<td>4. Animal model – live tissue</td>
<td></td>
</tr>
<tr>
<td>5. Animal model – cadaveric model</td>
<td></td>
</tr>
<tr>
<td>6. Manikin with realistic airway</td>
<td></td>
</tr>
<tr>
<td>7. Standard CPR manikin</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data sampling</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Continuous clinical data sampling</td>
<td></td>
</tr>
<tr>
<td>2. Manual registration by separate registrator</td>
<td></td>
</tr>
<tr>
<td>3. Manual registration by provider</td>
<td></td>
</tr>
</tbody>
</table>

A recently published Utstein-style template for uniform reporting of airway management data is made up of three sets of variables [38]. So far only one study has been published with data records corresponding fully to this style-set and it remains to be seen to what extent this template will be implemented in future studies [39].

As will be discussed later, the template lacks core variables on the clinical decision that subsequent advanced airway management is based on.
Table 4: The Utstein core variables
Variables suggested for uniform recording and reporting of data in studies on pre-hospital advanced airway management. Adapted from Sollid et al. [38]

<table>
<thead>
<tr>
<th>Core system variables</th>
<th>Core patient variables</th>
<th>Core post-intervention variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Highest level of EMS provider on scene</td>
<td>1. Co-morbidity</td>
<td>1. Post-intervention ventilation</td>
</tr>
<tr>
<td>2. Airway devices available on scene</td>
<td>2. Age</td>
<td>2. Post-intervention SBP</td>
</tr>
<tr>
<td>5. Response time</td>
<td>5. Indication for airway intervention</td>
<td>5. Post-intervention SBP on arrival</td>
</tr>
<tr>
<td></td>
<td>6. Respiratory rate, initial</td>
<td>6. Post intervention heart rate</td>
</tr>
<tr>
<td></td>
<td>7. Systolic blood pressure (SBP), initial</td>
<td>7. Post-intervention SpO2 on arrival</td>
</tr>
<tr>
<td></td>
<td>8. Heart rate, initial</td>
<td>8. Post-intervention ETCO2 on arrival</td>
</tr>
<tr>
<td></td>
<td>9. Glasgow Coma Score (GCS), initial (m/v/e)</td>
<td>9. Survival status</td>
</tr>
<tr>
<td></td>
<td>10. SpO2, initial, ± supplemental O2</td>
<td>10. Attempts at airway intervention</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11. Complications</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12. Drugs used to facilitate airway procedure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13. Intubation success</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14. Device used in successful airway management</td>
</tr>
</tbody>
</table>

1.2.2 The pre-hospital difficult airway algorithm
A difficult airway may in general be defined as the clinical situation in which a conventionally trained anaesthesiologist experiences difficulty with bag-valve-mask (BVM) ventilation, difficulty with ETI, or with both. Pre-hospital patients in need of RSI facilitated ETI are critically injured or ill and an increased rate of complications has been suggested [40]. The reasons for difficult airways are many and there is lack of a nomenclature or classification system. One reasonable way of describing the difficult airway has been proposed in the Practice guidelines for management of the difficult airway published by the American Society of Anesthesiologists (ASA) Task Force on Management of the Difficult Airway in 2013 (table 5) [41].

Table 5: Suggested descriptions of difficult airway by the ASA Task Force on Management of the Difficult Airway

1. **Difficult facemask or supraglottic airway (SAD) ventilation (e.g., LMA, ILMA, laryngeal tube):** It is not possible for the anaesthesiologist to provide adequate ventilation because of one or more of the following problems: inadequate mask or SAD seal, excessive gas leak, or excessive resistance to the ingress or egress of gas. Signs of inadequate ventilation include (but are not limited to) absent or inadequate chest movement, absent or inadequate breath sounds, auscultatory signs of severe obstruction, cyanosis, gastric air entry or dilatation, decreasing or inadequate oxygen...
saturation (SpO₂), absent or inadequate exhaled carbon dioxide, absent or inadequate spirometric measures of exhaled gas flow, and hemodynamic changes associated with hypoxaemia or hypercarbia (e.g., hypertension, tachycardia, arrhythmia).

2. **Difficult SAD placement**: SAD placement requires multiple attempts, in the presence or absence of tracheal pathology.

3. **Difficult laryngoscopy**: It is not possible to visualize any portion of the vocal cords after multiple attempts at conventional laryngoscopy.

4. **Difficult tracheal intubation**: Tracheal intubation requires multiple attempts, in the presence or absence of tracheal pathology.

5. **Failed intubation**: Placement of the ET fails after multiple attempts.

The difficult airway in a pre-hospital setting represents a complex interaction between patient factors, the emergency clinical setting, the operational situation, localization of the patient, available equipment and the skills of the practitioner and the assistant(s). A number of factors may increase the level of difficulty (table 6).

<table>
<thead>
<tr>
<th>Table 6: Challenges in pre-hospital airway management</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Patient and injury, blood and vomit in the airway</td>
</tr>
<tr>
<td>2. Light and temperature</td>
</tr>
<tr>
<td>3. Positioning of the patient</td>
</tr>
<tr>
<td>4. Complex clinical situation</td>
</tr>
<tr>
<td>5. Entrapped patients</td>
</tr>
<tr>
<td>6. Lack of fibreoptic scopes</td>
</tr>
<tr>
<td>7. Little time to anatomic assessment</td>
</tr>
</tbody>
</table>

Guidelines for management of the anticipated and unanticipated difficult airway have been published from different national societies and groups. Some have chosen to develop guidelines for specific patient types and/or scenarios. For instance the Difficult Airway Society (DAS) has developed guidelines for the non-obstetric, adult patient [42]. The guidelines published by the ASA Task Force on Management of the Difficult Airway recommend a structured prepared approach that involves a number of decisions that must be taken during the process (figure 13).

In the pre-hospital setting parts of the difficult airway flowchart will not be relevant. Patients are critically ill and the risk assessment must be made parallel to other clinical decisions on site. The same challenge has been reported from the emergency department (ED) [43]. In 2008 a task force from the Scandinavian Society for Anaesthesiology and Intensive Care Medicine (SSAI) published guidelines for pre-hospital airway management (figure 14). The work was motivated by the fact that there were few if any guidelines that focused on the pre-hospital airway management for all types of providers. The difficult airway algorithm in these guidelines were based on three levels of training
(basic, intermediate, advanced) and four techniques (chin lift/oropharyngeal airway, BVM, SAD, ETI) [44].

Figure 13: Flowchart ASA DA Guidelines

*The chart as published by the ASA Task Force on Management of the Difficult Airway – guidelines 2013*
Figure 14: Flow-chart for pre-hospital airway management

Note that some rare but challenging pre-hospital situations do not fit to such a guideline. If the airway is obviously blocked after trauma, the first step may be to perform a surgical airway because all other options are impossible.

In HEMS/GEMS, like in the different departments of anaesthesia, every unit has developed their local variants of difficult airway management guidelines. They are adjusted to fit the team of HEMS paramedic and HEMS anaesthesiologist and, in most cases, to the equipment that the HEMS anaesthesiologists use in-hospital. Routines are also adjusted to the available equipment. The key elements in pre-hospital difficult airway management guidelines are illustrated in figure 15.
Figure 15: Difficult airway algorithm elements in AS-EMS

After ONE unsuccessful intubation attempt

STEP 1 - OPTIMALIZATION

Apply BMV while optimizing the situation with one or more of the following:

- Better positioning?
- BURP adapted by assistant (BURP = back – up – right – pressure of trachea)
- Anterior part of cervical collar loosened?
- Cricoid pressure released?
- Anaesthesia adequate and patient fully relaxed?
- Change the size of Macintosh blade and/or ET tube?
- Use the bougie?

STEP 2 – NEW INTUBATION ATTEMPT IF REASONABLE

- If you do not want to perform more than one attempt, or if intubation is anticipated to be impossible due to facial trauma (but patient can still be ventilated), go directly to step 3.
- If attempt number two is unsuccessful; – the focus must be changed to ventilation and oxygenation!

STEP 3 – FOCUS ON VENTILATION AND OXYGENATION – CHOOSE ONE OF THREE OPTIONS

Option 1

BMV with oxygen while further optimizing continues:
- 2-person-technique?
- Oropharyngeal tube?
- More anaesthesia?
- Muscle relaxant?

New intubation attempt

YES

ILMA UNSUCCESSFUL AND PATIENT CAN NOT BE VENTILATED VIA BMV:

Cricothyreotomy

NO

ILMA UNSUCCESSFUL BUT PATIENT CAN BE VENTILATED VIA BMV:
- Continue with BMV

ILMA UNSUCCESSFUL AND PATIENT CAN NOT BE VENTILATED VIA BMV:
- Add Jet-catheter to improve oxygenation
- Continue to cricothryrotyotomy

Option 2

If BMV was unsuccessful during step 1: Apply Fastrach™ ILMA

YES

Continue with ILMA

NO

Wake up patient

Option 3

BMV with oxygen while waking up the patient

successful?
1.2.3 Discriminating between pre-hospital advanced airway management between patients with intact reflexes and airway management in victims of out-of-hospital cardiac arrest (OHCA)

Rapid establishment of a patent airway in the critically ill or injured patient is a well-known priority for both pre-hospital and in-hospital providers of emergency medical care [45]. The literature on pre-hospital airway management is confused by the fact that the healthcare providers may have very different education and skill level. Important confounders also exist in the terminology. The term advanced airway management, for instance, may be used very differently by different systems. Large differences in data recording and data reporting also exist. In a systematic literature review Lossius et al. extracted all available Utstein airway core variables from 76 original papers investigating ETI in adults [46]. Not surprisingly, core data required for proper interpretation of results were frequently not reported.

1.2.3.1 Rapid sequence intubation (RSI)

In an RSI an induction agent is administered followed immediately by a neuromuscular blocking agent to facilitate rapid ETI. The purpose of both in-hospital and pre-hospital RSI is to make emergency ETI easier and safer, thereby increasing the success rate of ETI while decreasing the frequency of complications like aspiration and hypoxia. RSI remains the standard of care in emergency airway management.

While the patient in cardiac arrest does not have reflexes, the non-cardiac arrest patient may suffer if ETI attempts are not preceded by RSI.

1.2.3.2 Airway management in cardiac arrest patients

Airway management in cardiac arrest patients is very different from patients with some degree of intact reflexes. In the field of airway management in out of hospital cardiac arrest (AMOHCA), recent developments in supraglottic airway devices (SADs) have changed the focus to evaluate alternatives to ETI. This is further discussed in chapter 1.3.

1.2.4 Pre-hospital ETI controversies in non-physician systems

The Cochrane review on effects of pre-hospital ETI published in 2008 was based on the randomized clinical trials available until 2006 of which all were performed in urban paramedic based systems. The authors concluded that for trauma and paediatric patients, the current evidence base provided no basis for extending the practice of pre-hospital ETI in these kinds of systems [47]. In a meta-analysis of 57,132 patients by Hubble et al., the success rate for oral ETI performed by non-physicians in non-cardiac arrest patients was found to be 70 % [48]. Interestingly, an annual decline of 0.49 % in success rate was calculated. One may speculate if this is due to the increasing number of providers and the increasing availability of SADs as an easier alternative to ETI [49]. Several large studies have continued to demonstrate worrying rates of unsuccessful ETI in North-American EMS systems [50]. In 2009 Elm et al. published a systematic review on the literature provided by seventeen studies including 15,335 patients receiving pre-hospital ETI due to TBI [51]. All studies were published in the
period 1985-2004, and were performed in systems with non-anaesthesiologists. The authors concluded that the available evidence did not support any benefit from pre-hospital ETI and mechanical ventilation after TBI. This conclusion, however, as pointed out by the authors themselves, is only valid in the context of these types of medical systems. In a systematic review focused on paramedic based systems only five studies enrolling a total of 1,559 patients were included [52]. Four of five studies compared different SADs with ETI. No individual study showed any statistical difference in outcomes between the ETI and the alternative airway management. The authors concluded that owing to the heterogeneity of pre-hospital systems, administrators of each system must individually consider their airway management protocols. The current recommendations from the American National Association of EMS Physicians (NAEMSP), American College of Emergency Physicians (ACEP), and American College of Surgeons Committee on Trauma (ACS-COT) is that drug-assisted ETI in the pre-hospital services may be used if there is strict control with quality, supervision and if safety guidelines are in place.

1.2.4.1 Guidelines on pre-hospital airway management

The SSAl guidelines for pre-hospital airway management concluded, based on the available literature available until 2008, that advanced airway management is potentially harmful in unskilled hands. In these guidelines pre-hospital ETI of traumatized patients and medical patients was suggested to be restricted to anaesthesiologists with experience in drug-assisted ETI. Only experienced EMS personnel were recommended to attempt ETI during CPR, on the criteria that repeated attempts should be avoided.

1.2.4.2 What training is needed to gain the adequate technical skills in ETI?

The low success rates among paramedics reported in the literature may, in part, be due to inadequate training. There is lack of literature on what training is adequate. In a Swiss study from 1998 eleven residents in anaesthesiology were observed during their training period. For ETI, a 90 % success rate was achieved after a mean of 57 attempts [53]. The annual requirement of ETIs to maintain the skills is not well documented, but the number 10 is often cited. In-hospital ETI rates are believed to be declining because of increasing use of SADs and regional anaesthesia for patients undergoing elective surgery. Consequently, fewer patients are available for in-hospital ETI training, rendering it more or less impossible for paramedics to achieve and maintain the necessary skill level. In a study on UK EMTs and paramedics 48 % of the providers had undertaken no ETI and 76 % had undertaken one or zero ETIs in the 12-month study period [54]. Similar low frequencies of LMA insertion attempts were reported.

Harris and Lockey reported from a prospective study where ETI success rates, quality of laryngeal view and number of ETI attempts were analysed against the background of the physician performing the procedure [55]. Doctors with a background in anaesthesia and consultant emergency physicians had a significantly better first-pass ETI rate than emergency medicine trainees. Quality of laryngeal view was reported as significantly better if laryngoscopy was performed by an anaesthesiologist.
Timmerman et al. studied 149 consecutive out-of-hospital ETIs performed by primary emergency physicians and found by on scene evaluation that the tracheal tube had been placed in the right mainstem bronchus or oesophagus in 16 (10.7%) and 10 (6.7%) patients, respectively [40]. This finding may be seen as evidence that substantial training and volume in advanced airway management is of great importance.

1.2.5 Variables frequently used for reporting quality of pre-hospital ETI
There are different systems for classification of the patient airway. The Cormack Lehane grading is widely used [56].

1.2.5.1 Success rate of pre-hospital ETI
Success rate of pre-hospital ETI is the single most important variable to describe the quality of the provider and the medical system. Although it does not provide information of how the ETI was performed it may be used as a marker of patient safety. For physician-based systems, the number of relevant studies that report ETI success rates has increased in recent years. Six of nine relevant papers have been published during the latest three years and all report a high success rate of 98-100% [55, 57-62]. This is comparable to in-hospital rates [63]. In a recent comprehensive meta-analysis of 58 articles reporting pre-hospital ETI in adult patients physicians were found to have significantly fewer pre-hospital ETI failures overall than non-physicians [64]. The authors suggested that basic or advanced airway techniques other than ETI should be strongly considered in systems based on non-physicians.

1.2.5.2 First pass ETI
First pass ETI is another way of expressing the quality of ETI. Unfortunately few authors report the number of attempts necessary for successful ETI. In the prospective study from London HEMS first pass ETI was performed in 88% of the cases [59].

1.2.5.3 Unrecognized oesophageal intubation
Unrecognized oesophageal intubation is a feared potential complication of ETI. The incidence of this complication may be seen as an important quality parameter. Recent studies on safety of physician based ETI report that all misplaced ETs are identified and corrected [65]. However, there may be an important difference between anaesthesiologists and emergency physicians if the latter have had insufficient airway management education [40].

The rate of unrecognized paramedic oesophageal intubation has been reported as high as 16.7% [66]. An incidence of unrecognized misplaced tubes of 9% was reported in another study from the EMS in New York, USA [67]. Another 15% of the ETs were placed in the right main bronchus. One disturbing fact with these two studies is that the verification of misplacement happened in the ER. Thus the patients probably had a misplaced tube for a long period of time. In CPR and absence of an adequate clinical competence, there are few technical ways of detecting the misplaced ET. Capnography is of limited benefit, and CO₂ in the stomach of patients that have received bystander
CPR with mouth-to-mouth ventilation may in fact be monitored as a false capnographic signal after oesophageal intubation [68].

Dislocation of the ET may occur in any phase of the pre-hospital care. When moving the patient flexion of the neck may change the position of the ET in trachea so that dislocation may occur. This is more likely in children than in adults, and the risk increases if the depth of the ET is incorrect or if continuous observation is not maintained. No good data exists on the frequency of this problem. Most modern HEMS systems pay attention to this risk and train their teams to use neck-collars and maintain a mental cervical spinal immobilization while moving non-trauma patients.

1.2.5.4 Importance of continuous data sampling
Most pre-hospital advanced airway management studies in the last part of the 20th century were of variable quality and based on vague endpoints. Lack of technology for continuous sampling of data may have been one reason for this. With the publication from Dunford et al. more reliable and shocking data were published [69]. In this study continuous recordings of pulse oximeter values and heart rate were made during pre-hospital drug facilitated ETI in a paramedic-based EMS in San Diego. An incidence of desaturation of 57 % was demonstrated. 84 % of these events occurred in patients where basic airway skills maintained pulse oximetry values greater than or equal to 90 % prior to the ETI. Another worrying finding was that the paramedics described RSI as "easy" in 84 % of the patients with desaturation. The authors pointed out that suboptimal pre-oxygenation may have been an important factor and had to be further investigated. The trial was stopped and the authors concluded that pre-hospital RSI is “an inherently dangerous procedure that requires personnel fully trained and competent to anticipate and prevent the significant physiologic derangements that can occur.”

In a subsequent study the findings were followed by matched-controls analysis confirming an association between hypocapnia and mortality and between hypoxia and mortality in TBI patients. Hyperventilation and severe hypoxia during paramedic RSI in this system was reported to increase mortality from 22 % in the control group to 41 % in the paramedic RSI group [70].

The publications from San Diego started an intense debate on safety of pre-hospital RSI. The findings, among other factors, motivated the research that initiated this thesis and probably motivated the anaesthesiologist and emergency physician based (H)EMSs in Europe to evaluate and publish their data.

1.3 SADs and video laryngoscopes

1.3.1 SADs
SADs can be used in a number of pre-hospital advanced airway management settings. These can be summarized as follows:
1. SAD as primary device or as an alternative to ETI in paramedic based airway management during CPR in OHCA
2. SAD as primary device in OHCA to reduce no flow time (NFT), independent of provider skills
3. SAD as rescue device in cases of “cannot intubate” during both CPR and during RSI procedures
4. SAD as rescue device in “cannot intubate – cannot ventilate” (CICV) scenarios
5. SAD as primary device for airway management in special circumstances, for instance in entrapped patients

1.3.1.1 Description of SADs
The name SAD reflects the fact that SADs are not inserted past the vocal cords into the trachea. Thus there is no need for laryngoscopy or other means of direct visualisation of the vocal cords for their insertion. A thorough description of the historical development of SADs has recently been published [71]. The most relevant alternatives that are used in some Scandinavian EMS systems are listed in Table 7.

There has been a rapid development of new interesting devices. They are all primarily developed for in-hospital elective anaesthesia or as tools for difficult airway management. The amount of literature on in-hospital use of SADs is large, but very limited on pre-hospital use. The differences in skills in Norwegian HEMS are anticipated to be small, because HEMS anaesthesiologists work regularly in-hospital as consultant anaesthesiologists. Thus in-hospital studies can be very relevant for this group.

1.3.1.2 Classical LMA
Although originally designed for elective anaesthesia, the LMA rapidly gained success in emergency care. High success rates have been demonstrated among inexperienced providers, and some studies suggest that the placement and use of LMA is simpler than ETI [72, 73]. However, recent studies have modified this impression [74].

Inexperienced health care workers may provide more secure and reliable ventilation with LMA than with BVM ventilation in OHCA [75, 76] and the LMA is recommended in the ERC resuscitation guidelines [77].

Variants of LMA are the intubating LMA (ILMA) and the LMA Proseal™. The latter may be somewhat more difficult to place for the inexperienced provider. The ILMA has gained a good reputation as a back-up device in difficult airway management and is discussed below.

1.3.1.3 Laryngeal tube (LT) with suction (LTS-2)
Manikin studies report high success rates [78, 79], but Sunde et al. recently reported a high number of insertion related problems, indicating that SADs may be less reliable in real-life resuscitations [80]. A German study reported similar findings [81].

1.3.1.4 i-gel™
High insertion success rate with very few complications has been reported in paediatric patients. In fifty children above 30 kg undergoing short-duration surgery all airways were secured with i-gel™ on
the first attempt [82]. The success rate was higher with i-gel™ (94 %) than with ETI (90 %) during CPR in a UK ambulance service [83]. In a German observational study of i-gel™ use during CPR a 90 % first attempt insertion success rate was found; 7 % succeeded on the second attempt, and the remaining 3 % on the third attempt. There was a significant association between ease of insertion and the quality of the seal and ventilation during CPR was adequate in 94 % of all CPRs [83]. In a clinical Italian study with novice providers first time success rate was higher, failure rate lower, and the seal better with LMA Supreme™ than i-gel™, indicating that LMA Supreme™ may be preferable for emergency airway use by novices [84].

1.3.1.5 ILMA Fastrach™

The ILMA has been proposed for emergency airway management because its insertion technique is somewhat simpler than that for the LMA due to a more rigid construction. Normally there is no need for digital manoeuvres to correctly place the ILMA in the patient. In a large French material on pre-hospital ETI and difficult airway management, the large majority of cannot intubate cases were solved with ILMA [85].

Table 7: Frequently used SADs in Scandinavian (H)EMS systems

The illustrations are adapted from the article by Bjerkelund et al. [86]

<table>
<thead>
<tr>
<th>Illustration</th>
<th>Name</th>
<th>Sizes</th>
<th>Most frequent indication for use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Classic LMA</td>
<td>Available in all sizes, from premature infants to adult sizes (5-100 kg)</td>
<td>Used as back-up device in children by most Norwegian HEMS</td>
</tr>
<tr>
<td></td>
<td>Options with suction: - Proseal™ - Supreme™</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LT with suction (LTS) - “LTS-2”</td>
<td>5 kg – adult (180 cm)</td>
<td>Used in OHCA by paramedics</td>
</tr>
</tbody>
</table>

Table 7: Frequently used SADs in Scandinavian (H)EMS systems

The illustrations are adapted from the article by Bjerkelund et al. [86]
### 1.3.1.6 Safety of SADs in pre-hospital EMS

With the exception of the older endotracheal combitube (ETC), SADs are not supposed to be inserted into the trachea. For paramedics and non-skilled airway management providers, SADs have become a very relevant new tool for airway handling during CPR. In assessing the safety of each SAD, different quality factors must be studied.

In emergency cases, patients must be assumed to have a full stomach and thus an increased risk of regurgitation. SADs do not fully seal the lower airways from blood and debris. On a cadaveric model large differences between LMA ProSeal™, classic LMA and i-gel™ were found. One minute after maximum pressure had been applied, LMA ProSeal™ withstood an oesophageal pressure of 59 cm water, Classic LMA a pressure of 46 cm, and i-gel™ a pressure of 21 cm water [87].

#### 1.3.1.6.1 Relevance of manikin based training

Manikin studies indicate that SADs have a steeper learning curve and better skill retention when compared to ETI [88]. Whether manikin training alone is sufficient remains to be answered. The discrepancy between reported success rates in manikin studies and in patients is worth debating and is further discussed in part II of this thesis.

#### 1.3.1.6.2 SADs in OHCA - can LMA reduce no flow time in the initial phase of CPR?

In a randomized prospective study on simulated CPR the LTS-D was inserted significantly faster than the ET (15 s vs. 44 s, respectively, p < 0.01) [89]. This, and several other manikin studies all suggest that SADs like LTS-D significantly reduced NFT compared to ETI [79, 90]. SADs like the LTS-2 have been advocated in the ERC guidelines for CPR [77]. In a large manikin based study on six different airway management techniques, the mean hands-off time associated with ETI was 48 seconds.
Interestingly NFT with i-gel™ was 15.9 seconds compared to only 8.4 seconds using the LT and NFT was significantly longer with the conventional ET than with any of the other airway devices. Moreover, only a third of the EMTs successfully inserted an ET whereas all of them successfully positioned each SAD [91]. In the follow-up, EMTs achieved a NFT within the recommended time limit of 10 seconds, even after three months without any training or practice [92]. However, in a recent study Sunde et al. report a high number of insertion related problems, indicating that SADs may be less reliable in real-life resuscitations [80]. LT insertion was successful in 85 % of the patients, with a 74 % first-attempt success rate. A similar study from a German EMS reported first pass success rates above 90 % [90]. No controlled trials exist that compares advanced airway management to basic airway management and a recent systematic review and meta-analysis is inconclusive due to the lack of adequate studies [93]. A randomized clinical trial has recently been initiated in the UK. The goal is to compare the ventilation success of two newer SADs: the i-gel™ and the LMA Supreme™ to usual practice during the initial airway management of OHCA [94].

Several studies focus on the NFT during CPR. Interesting alternative questions regarding the role of SADs in CPR have been raised by Japanese researchers. In a porcine model decreased carotid artery blood flow has been demonstrated with use of three different SADs (King LTS-D™, LMA Flexible™, Combitube™) [95]. However, no study has investigated if the volume of SADs negatively impacts carotid artery blood flow during CPR in humans. A nationwide population-based observational study of all registered OHCA patients in Japan over a 3-year period reported that pre-hospital use of SADs was associated with slightly, but significantly, poorer neurological outcomes compared with ETI [96].

1.3.2 Video laryngoscopes in the pre-hospital environment

Direct laryngoscopy is the technique of choice if a secure airway must be obtained. Recent technical development of video and optical based devices for laryngoscopy has provided the pre-hospital services with a number of expensive tools. The video and optical laryngoscopes are more solid than fiberoptic based broncoscopes and thus may be used in the pre-hospital environment. Some of the products available in Scandinavia are Storz V-Mac®, Storz C-Mac®, Glidescope®, McGrath®, Pentax Airway Scope®, Airtraq® and Bullard [97].

The Glidescope® was the first available product in 2001. It incorporates a digital camera, connected by a video cable to a high resolution LCD monitor. It can be used for ETI, as well as for removal of foreign bodies from the airway. In a recent systematic review and meta-analysis Glidescope® video-laryngoscopy (VL) was associated with improved glottic visualization, particularly in patients with potential or simulated difficult airways compared to direct laryngoscopy [98].

The literature suggests that VL should be used as the primary technique when urgent ETIs are performed by less experienced operators [99]. This is the case in a number of military medical services, and this is the only pre-hospital setting where one may argue that VL is widely used. In the hands of experienced providers rates of successful ETI on first attempt are not significantly different between VL and direct laryngoscopy [100]. In fact, ETI using VL seems to be more time consuming.
The literature on VL as a tool for difficult airway management is conflicting. Some reports are positive [101]. Arguments are made that all patients with a suspected C-injury should be intubated by use of video laryngoscopes [102, 103].

In entrapped patients the results are also conflicting. When attempting to intubate a trapped car accident victim, VL may provide a better view of the glottis, but may delay ETI significantly. The devices with a tube guide (Airtraq® and Pentax Airway Scope®) enable ETI to be achieved significantly faster and with a lower failure rate than devices without a tube guide. No video laryngoscope outperformed direct laryngoscopy with a Macintosh laryngoscope in a recent manikin based study [104].
Part II – Introduction to key issues in airway management provided by anaesthesiologist based pre-hospital emergency medical services

2.1 On scene time (OST) and tactical aspects

In principal the Norwegian HEMS is able to provide society with two unique qualities:

1. Increase the geographical availability of a specially prepared team based on the skills of anaesthesiologists
2. Reduce response time and transport time of patient to the adequate hospital.

To make the optimal positive impact on patient outcome, HEMS needs to be dispatched in a fast and precise way based on the right dispatch criteria. On site, the crew must perform diagnostic work and the necessary treatment before loading the patient for transport to the adequate hospital.

Transportation to definitive intervention may be delayed by a number of factors, but some of them can be prevented. Others are due to patient or accident factors. The most important preventable factor may be the one most difficult to grasp: EMS with sufficient knowledge to plan the patient route before arrival of HEMS. This means that the patient is prepared and moved so that OST is minimized. Other preventable factors are the different skills of the HEMS team. Both the ability to make a fast and precise clinical decision and to perform the necessary treatment are important.

OST may for instance be increased by multiple ETI attempts at the scene of the accident, especially if the sequence of actions is not well planned and trained. In a Danish study, the presence of an anaesthesiologist prolonged the median on-scene time by 1 min and in cases of pre-hospital ETI by 7.5 min [105]. In an American study time cost was estimated to be 2.6-3.7 min, depending on what additional procedures (e.g., airway management, suctioning, vascular access, CPR) were required [106]. Although of interest, these data are difficult to interpret, especially because data describing the tactical work is lacking.

In a study from the HEMS in Stavanger, Norway, analysis of a ten year database material found the mean OST in missions where patients were RSI intubated to be longer (23 minutes ± 13) than in trauma missions where such treatment were not necessary (11 minutes ± 11) [107]. Interestingly performance of RSI intubation was associated with longer mean transport times (22 minutes ± 16 vs.
13 minutes ± 14). The latter may be explained in part by increased inclination to secure the patients airways with increasing transport time.

Some US studies have focused on pure geographical criteria for use of helicopters. In one study ground ambulance transport provided the shortest total time to delivery in hospital at distances less than 16 kilometres (10 miles) from the hospital. At longer distances simultaneously dispatched air transport was faster. Non-simultaneous dispatched helicopter transport was faster than ground if greater than 83 kilometres (45 miles) from the hospital [108].

The pure technical perspective to helicopter transport has been criticized. Arguments are made that mode of transport in trauma missions should be based upon multiple factors including the distance traveled and ambulance availability, and must be individualized for each site that transfers patients [109]. In a European and Scandinavian perspective, one important additional factor is the availability of a higher competence level if HEMS is dispatched to the trauma patient. Unfortunately, there is lack of literature describing more tactical elements of helicopter use in primary trauma missions.

Thus there is a need to study the operative and tactical aspects of HEMS. This is reflected in the first aim of this thesis.

2.2 Pre-hospital ETI

Some European EMS system use teams based on pre-hospital anaestheziologists to provide the same quality of ALS as inside the hospital. RSI facilitated ETI is a necessary procedure, but with potential risks. Success rates of 97-100 % seem to be the case in all major studies [59, 110-112]. Success rate, however, is one of many variables needed to control the safety of this procedure. Pre-hospital patients are subject to acute illness or injury. They are located in suboptimal environments and are not subjected to a preparation and anatomical evaluation, as would be the case in elective general anaesthesia. In a study by Helm et al. factors that made laryngoscopy more difficult during pre-hospital RSI were blood (19.9 %), vomit/debris (15.8 %) and secretions (13.8 %) in the upper airway; anatomical reasons (11.7 %), patient position (9.6 %) and surrounding conditions (9.1 %) [112].

In the subpopulation of patients with TBI it is of critical importance to prevent desaturation and hypotension during ETI. A few pre-hospital patients are respiratory and/or circulatory unstable and may be difficult to preoxygenate. Thus a special focus should be made on factors increasing the risk of difficult airway and desaturation.

2.2.1 Results from a Norwegian questionnaire based study

A number of additional risk factors may exist when especially trained teams with anaesthesiologists and emergency physicians provide ETI. In a study on Norwegian HEMS anaesthesiologists, 77 % reported having experienced difficult ETI cases and 3 % had experienced failed ETI [107]. Significantly more full-time than part-time HEMS physicians had experienced these problems, which may reflect
their larger exposure to pre-hospital ETI. In the same study 29 % reported that they were not familiar with all the equipment for difficult airway management.

2.2.2 Frequency of desaturation in relevant studies
In a prospective observational study of 208 consecutive adult and paediatric patients Reid et al. investigated the incidence of complications (including hypoxaemia and hypotension) when RSI was performed either in the ED or in the hospital wards [113]. The authors reported an incidence of hypoxaemia (defined as SpO2 below 90 %) in 19.2 % of the patients and an incidence of hypotension in 17.8 % of the patients. This study is one of few to report the incidence of hypotension in emergency RSI. In a study of adverse events in pre-hospital RSI in London HEMS published by Newton et al., a frequency of desaturation of 18.3 % was reported for trauma patients [59]. In an Australian HEMS audit of pre-hospital RSI a success rate of 97.6 % could be documented, but no frequency of desaturation was reported [110]. One interesting finding was the relatively high frequency of a difficult airway of 9.3 %, which corresponds to the findings in the German HEMS.

2.2.3 Hypotension as an adverse effects to RSI
No pre-hospital studies have reported the frequency of hypotension as a quality marker of RSI. Newton et al. speculate that if a SBP of 95 mmHg is used as the limit in the London HEMS material, the frequency of hypotension would be about 19 %.

Our study was the first that focused on safety of pre-hospital RSI in the Norwegian Air Ambulance Service. The study by Newton et al., which was published while our study on RSI was running, was the first study that provided relevant data on incidence of desaturation in a system with HEMS physicians. However, in that study no continuous data were recorded and the authors pointed out the need for further research in the field of airway management in anaesthesiologist based pre-hospital emergency medical services. This is reflected in aim 2 of this thesis.

2.3 Airway management in entrapped patient

Advanced airway management of entrapped patients is challenging but occurs infrequently. In some cases patients are in need of assisted ventilation while still sitting in the wreckage. OHCA is frequent and numerous patients are located in confined areas.

If access to the cranial end of the patient is impossible, conventional laryngoscopy has been considered to be too unsafe in most cases, and alternatives to ETI with a Macintosh laryngoscope have been sought. The incidence of this clinical situation is unknown and the available literature is restricted to various studies on simulated entrapment by use of arranged manikins.

Recently the inverse intubation method as an additional approach for intubation in the out-of-hospital setting has received renewed attention. Using four case reports, situations in which inverse intubation may be an important tool for successful airway management are discussed. Other uses of
the method are listed [114]. Inverse intubation is a useful skill for pre-hospital providers. This skill can be taught in a brief period and used successfully with no compromise in speed or success rate [115].

In a French study the Airtraq™ laryngoscope was found superior to both the GlideScope™ and LMA Fastrach™ during simulated face-to-face difficult tracheal intubation [116].

In another manikin based study direct laryngoscopy, indirect optical laryngoscopy with Airtraq® and VL with McGrath® were compared. The manikin was sitting with the neck immobilised and only accessible from the left anterolateral side. Surprisingly inverse direct laryngoscopy showed reasonable intubation times and the authors concluded that given the widespread availability of Macintosh laryngoscopes, it seems to be a useful technique [117].

In a manikin model of restricted airway access, ET, ECT, and LMA were compared to investigate which method was the fastest to result in successful ventilation in three non-traditional pre-hospital airway scenarios. LMA was faster in two of three scenarios [118].

Given these very limited data, one may suggest that there are four possible strategies to handle the airway in an entrapped patient if BMV is not possible:

1. Face-to-face direct laryngoscopic intubation
2. Use of an LMA (for instance ILMA)
3. Use of a indirect video laryngoscope (Airtraq®)
4. Use of a direct video laryngoscope

One vital issue must be addressed. All studies on entrapped patients are based on arrangements of manikins. Will the participants learn the anatomy of the manikin and thus overperform? This is discussed in part 2.4.

The recent development of field friendly video laryngoscopes is very interesting. This is reflected in aim 3 in this thesis.

2.4 Training effect of using fixed airway simulators and manikins in basic SAD training

Entrapped patient scenarios are rare, but challenging. A number of different approaches are possible. It is of interest to study different techniques in an HEMS/GEMS setting. The recent development of modern SADs is of great interest. This is reflected in aim 4 in this thesis.

As mentioned earlier, a number of studies in this field are based upon use of airway simulators or manikins. This has been strongly criticised [119]. Thus another aim of this thesis is to add to the knowledge on the training effect, as reflected in aim 5.
2.5 Pre-hospital cricothyrotomy

A number of critically ill or injured patients need immediate airway management including ETI in the field. The reported need for emergency cricothyrotomy varies but is generally below one percent when pre-hospital ETI attempts are made by anaesthesiologists and experienced emergency physicians [58, 59, 62, 111, 120]. In two reports from services staffed with surgeons or flight nurses, a frequency above 10% is reported [121, 122].

Independently of the medical system, occasionally a “cannot intubate – cannot ventilate” (CICV) situation will occur. In such instances, most airway management guidelines recommend that an emergency cricothyrotomy should be performed [41, 44, 123]. A number of techniques and devices have been developed to simplify the procedure. A recent systematic review is inconclusive with respect to the superiority of any one of the techniques [124].

The classic emergency surgical airway and the refined “rapid four step technique” (RFST) are both performed with an incision through the cricothyroid membrane and the use of a tracheal hook and/or dilators to secure the opening before a tube is advanced into the tracheal lumen [125, 126]. The “bougie-assisted emergency cricothyrotomy” (BACT) described by Hill and et al. is the most recent refinement [127]. This technique makes use of simple equipment including the bougie that may be used in earlier phases of the difficult airway algorithm as well. In BACT, a single stab incision is made through the cricothyroid membrane and a bougie is used to secure the access before an ET is inserted into the tracheal lumen. A tracheal hook is angled caudally and – if necessary – a Trousseau dilatator is used to secure access to the tracheal lumen.

The commercial kits for emergency cricothyrotomy can be divided into two broad categories. One group consists of kits based on the Seldinger technique that punctures the cricothyroid membrane followed by the insertion of a guide wire through the needle. These kits include the Arndt emergency cricothyrotomy catheter set, the Melker wire-guided cricothyrotomy set and the Minitrach II® [128-130]. The other group of commercial kits are based on a cutting device that creates a lumen in the cricothyroid membrane that is sufficiently wide for the insertion of the ET included in the kit. Examples of such products are the QuickTrach2® kit and the Portex cricothyrotomy kit (PCK) [131-133].

The PCK has been a part of airway management equipment in several Norwegian EMS in recent years [131]. Despite the availability of the device, an evaluation of the activity of the Oslo University Hospital HEMS revealed that when an emergency surgical airway was needed, the anaesthesiologists appeared not to prefer the PCK but instead used a modified RFST technique.

With the large number of available techniques and devices for emergency pre-hospital cricothyrotomy and an infrequent need of the intervention in real life, it is of great interest to evaluate the most promising methods. This is reflected in aim 6 of his thesis.
Part III - Aims of the thesis

3.1 Introduction

This thesis comprises five studies relevant for modern anaesthesiologist based EMS. It focuses on safety of pre-hospital RSI and feasibility of alternative airway management techniques that may be needed in difficult airway scenarios or when patients are entrapped at the accident scene.

3.2 The main aims

1. To investigate how close to the patient the HEMS helicopter is able to land in trauma missions and calculate OST in trauma missions and to what extent the need to perform an RSI intubation influences the OST.

2. To establish the frequency of desaturation, success rate and use of adjuvant clinical tools when performing RSIs in the field.

3. To evaluate the feasibility of VL in simulated scenarios of entrapped patients.

4. To compare the time consumption between ETI and use of two different SADs in simulated advanced airway management and in simulated entrapment of the patient.

5. To evaluate to what extent there is a training effect when using a fixed airway simulator for evaluation of airway management techniques.

6. To evaluate if there is a difference in performance at baseline level and after training with percutaneous and surgical techniques for cricothyrotomy in a cadaveric porcine airway model.
Part IV - Material and Methods

4.1 Paper I – prospective observational study

This study investigates some details of the operational aspects of HEMS trauma missions.

A study focusing on helicopter landing sites and injury severity, as defined by the need for RSI in trauma patients, was undertaken. The objective was to evaluate how the landing site, as determined by distance to the patient, and the injury severity affected the OST. In this prospective study four HEMS anaesthesiologists were educated to observe and record key operational data in trauma missions with focus on the landing site and on OST.

A detailed questionnaire regarding the landing sites and other data pertaining to the incident was completed in all missions, in addition to the standard transport chart. Data on type of landing site, distance from landing site to patient site, means of extra transportation (if needed), and degree of difficulty in reaching the patient were recorded. Operational data and frequency of medical interventions were extracted from the HEMS database. Interhospital transports of trauma patients and primary missions to trauma patients in which the crew responded by the RRC were excluded from the study. Further, helicopter missions that were aborted for various reasons (e.g., bad weather conditions or information from the ground EMS) were excluded.

4.2 Paper II – prospective observational study

This study investigates in detail the effects of pre-hospital RSI on SpO₂ in medical and trauma cases attended by physicians affiliated with the Oslo University Hospital HEMS in Norway.

Prospective, observational data concerning pre-hospital RSIs performed by the HEMS physicians were collected during a 12-month period starting April 1, 2008. Only cases requiring RSI were included in the study. Patients with OHCA, independent of aetiology, were therefore excluded from the study. Data related to the patient (age, sex, mechanism of injury, injuries/illness, and GCS on arrival of the HEMS) or to the airway management (indication for RSI, the Cormack Lehane grade of laryngoscopy, number of ETI attempts, and use of alternative airway devices) were recorded [16].

The regional ethics committee approved the study. SpO₂ was recorded in four-second intervals from arrival of HEMS, during preoxygenation, and for 10 minutes after induction of anaesthesia and ETI. A portable unit monitored SpO₂, 3-lead electrocardiogram, and blood pressure during transport. Cases where the recording pulse oximeter failed to detect a signal were excluded from the study. ETCO₂ was measured continuously. Anaesthesia was maintained with ketamine supplemented with titrated
doses of midazolam and/or fentanyl. Pancuronium for prolonged muscular relaxation was given if necessary.

4.3 Paper III – simulation study with use of one airway simulator

Airway management of entrapped patients is challenging and alternatives to ETI with a Macintosh laryngoscope must be considered. In this study, the GlideScope Ranger® video laryngoscope was evaluated as an alternative to standard laryngoscopy.

Eight HEMS anaesthesiologists intubated the trachea of a Laerdal SimMan® manikin using the studied laryngoscopes in two scenarios: (A) unrestricted access to the manikin in an ambulance and (B) no access from the head end, simulating an entrapped patient. The time used to secure the airway and the scored level of difficulty were the main variables. A Laerdal SimMan® manikin was used for both scenarios. The manikin was configured with the retropharyngeal balloon inflated, but without a fixated neck, in order to achieve direct laryngoscopy views corresponding with Cormack Lehane grades 1 and 2 during direct laryngoscopy. This is representative for the majority of the patients encountered in the field and the study focused on whether the GlideScope Ranger® was useful for airway management in a typical, entrapped patient. The manikin was placed in a supine position on a 55-cm-high stretcher in an ambulance. The anaesthesiologist had limited, but sufficient access from the seat at the head end of the manikin to perform a traditional ETI.

4.4 Paper IV – simulation study with use of two different airway simulators

The aim of this study was to compare the use of the SADs i-gel™ and LTS-2™ with traditional ETI in manikins in settings designed to mimic airway management in entrapped patients.

The twenty study participants were specialists in anaesthesiology employed by the Oslo University Hospital HEMS. None of the participants had extensive experience with the i-gel™ device in a clinical setting prior to this study. Only five of the participants had used it clinically within the previous two years. All participants were familiar with the LTS-2™ as a backup device, but only two had used it clinically within the previous two years. Based on preliminary testing, the Airsim Standard™ manikin head was selected for intubation procedures and the Airway Management Trainer™ manikin head was selected for use with the SADs. The main criteria for choosing the two manikins was that we were able to demonstrate little variability in insertion times with identical techniques performed by the same person. Older manikins demonstrated high variability in insertion times and thus were regarded as unfit for this study.
4.5 Paper V – prospective, randomized, crossover simulation based trial

With the large number of available techniques and devices for emergency pre-hospital cricothyrotomy and an infrequent need of the intervention in real life, it is of great interest to evaluate the most promising methods. Thus, the aim of this study was to evaluate the performance of the two locally available techniques when performed by air ambulance anaesthesiologists in both a baseline setting and after extensive training.

This was a prospective, randomised, crossover trial comparing PCK and BACT in a porcine airway model. Twenty air ambulance anaesthesiologists with a median post-graduate experience of 15 years (range 8-29) participated. None of the participants had extensive experience with either technique. All participants, however, had performed emergency cricothyrotomy in a porcine model with PCK and BACT during skill training one year prior to the present study. Six of the participants had previously performed an emergency cricothyrotomy in a real CICV-setting. A model based on larynxes from adult pigs was developed. The porcine larynx was fixed on a stand and covered with three layers of chicken skin to achieve realistic anatomy with respect to landmarks and sliding layers of tissue. Access to the larynx was restricted due to a manikin head located in an anatomically correct position cranially of the laryngeal model. Before each test, the larynx was inspected to ensure that there was no damage to the anatomical structures. The porcine larynx was replaced after each procedure and examined for grading of the tracheal wall lacerations and damage to the cartilage..

4.6 Statistical analysis

4.6.1 Paper I
Data were analysed using an Excel spreadsheet and the statistical package Epi-Info. Wilcoxon’s signed ranks test was employed for non-parametric data.

4.6.2 Paper II
Data were analysed using an Excel spreadsheet and the statistical package Epi-Info. Frequencies were compared with the \( \chi^2 \) test and Fisher exact test. Wilcoxon’s signed ranks test was used for other nonparametric data.

4.6.3 Paper III
Statistical analysis was performed using Epi-info for the use of the non-parametric Mann–Whitney/Wilcoxon’s two-sample test and the \( w_2 \)-test for comparison of the success rates. The chosen level of significance was \( P<0.05 \).
4.6.4 Paper IV
Data were analysed using an Excel spreadsheet and the statistical package Epi-info. The $\chi^2$ test and Fisher’s exact test were used for comparing frequencies. Wilcoxon’s signed ranks test was employed for other nonparametric data.

4.6.5 Paper V
Data were analysed using Excel 2010, PASW Statistics version 18, and GraphPad. Fisher’s exact test was used for comparing frequencies, unpaired $T$-test was employed for parametric data and the Kruskall-Wallis test with Dunn was employed for non-parametric data. Parametric data were presented as the means with standard deviation (SD), whereas non-parametric continuous data were presented as the medians with inter-quartile range (IQR). Ordinal data and categorical data were presented as number and frequencies.
5.1 Paper I

A total of 252 primary trauma missions were included in the study. In 75 % of the missions, the aircraft landed less than 50 meters from the scene, and in 7 % the distance exceeded 200 meters. Mean OST when the patient was not intubated was 14.5 minutes (median 14 min). When an RSI was performed, the mean OST was significantly higher (22.7 min, median 20 min; p<0.001). CONCLUSION: Usually, a helicopter can land close to the accident scene and the location of the landing site does not contribute to a delay in arrival of the patient at the hospital. The OST is significantly higher, when the patient is intubated before take-off. This reflects the time needed for the RSI, as well as the increased complexity and workload when the patient is severely injured [134].

5.2 Paper II

A total of 2,621 patients were investigated, resulting in 122 (4.7 %) pre-hospital RSI attempts. Trauma patients undergoing RSI (36.1 years) were significantly younger than the patients intubated for medical reasons (43.8 years, P = .049). There was no significant difference in gender, with men dominating both groups. There were complete SpO2 recordings for 101 (82.8 %) of the 122 ETI procedures. There was a higher tendency of incomplete registrations in trauma patients (20.2 %) compared with medical cases (11.6 %), but the difference was not statistically significant (P = .22). Information regarding duration of RSI was available in 55 (69.6 %) trauma RSIs and 34 (79.0 %) medical RSIs. In the remaining cases, registration of start or termination times of the procedure was incomplete. On average, an RSI took 40.8 seconds (SD, 17.5 seconds; range, 20-96 seconds). The duration of the procedure in trauma patients (mean, 41.3 seconds; SD, 16.7 seconds; range, 20-96) and medical patients (mean, 39.0 seconds; SD, 18.9 seconds; range, 20-88) was comparable (P = .44). The Cormack Lehane grade of laryngoscopic view and the level of ETI difficulty as perceived by the intubator were reported. No significant differences were found between the groups. The airway was successfully secured in 121 cases (99.2 %). All trauma patients were successfully endotracheally intubated on the first or the second attempt. In medical cases, a third ETI attempt was necessary twice (4.7 %). In one case, the ETI attempts were aborted after three unsuccessful tries, and the airway was secured with a LT, without recorded negative consequences for the patient. In another case, the RSI was performed with a McCoy laryngoscope after unsuccessful ETI attempts with a Macintosh laryngoscope.

Desaturation occurred in 11 (10.9 %) of the 101 patients with complete recordings. There was no statistically significant difference between trauma patients (11.1 %) and medical patients (10.5 %, P =
.93) in this respect. In five patients with initial SpO₂ above 90 %, SpO₂ decreased below this value (range, 30 %–89 %) during or within the first three minutes after completion of RSI. Two of these recording demonstrated a drop of more than 25 %. Six of seven patients that had an initial SpO₂ below 90 % had an SpO₂ decrease of more than 10 % during RSI or within the subsequent three minutes. Eight of the 11 patients who experienced desaturation recovered and maintained the SpO₂ values above 95 % during transport. The remaining three hypoxaemic patients were circulatory unstable. Reduced glottic view (Cormack Lehane grade 3 or 4) and multiple ETI attempts were not associated with increased incidence of desaturation events. Five cases of hypoxaemia were, however, associated with insufficient preoxygenation including two patients that had facial/oral trauma. There were no significant differences regarding patient characteristics when comparing patients who had hypoxaemic episodes with those who did not. Some factors that caused the physician to report “difficult” or “very difficult” intubation were reported. These problems did not, however, influence frequency of desaturation events.

5.3 Paper III

All participants successfully intubated the manikin in scenario A with both the Macintosh laryngoscope and the GlideScope Ranger® on the first attempt within the 60 seconds time limit. In scenario B, four out of eight (50 %) anaesthesiologists succeeded in blind, inverse ETI with the Macintosh laryngoscope on the first attempt within the time limit. The remaining four participants were unsuccessful. In this scenario, all anaesthesiologists successfully performed ETI with the GlideScope Ranger®. The success rate in scenario B was significantly higher with the GlideScope Ranger® than with the Macintosh laryngoscope (P<0.025). There were no significant differences in the time spent on ETI in the two scenarios or between the devices. When using the Macintosh laryngoscope, the Cormack Lehane score was 1 or 2 (glottis completely or partly visible) for all anaesthesiologists in scenario A and 4 (no view of the glottis or the epiglottis) in scenario B. With the video laryngoscope, all participants scored 1 or 2 in both scenarios. The subjectively scored level of difficulty was 1 or 2 (‘easy or moderate’) in scenario A and 4 (‘very difficult’) in scenario B with the Macintosh laryngoscope. When using the GlideScope Ranger®, all scored one difficulty level higher, that is, 2 or 3 (‘moderate’ or ‘difficult’), in both scenarios. All anaesthesiologists reported that this was due to difficulties in introducing the ET into the trachea of the manikin despite a clear glottic view. The participants stated that they found that the GlideScope Ranger® could be useful in both scenarios, while none would have attempted ETI with the Macintosh laryngoscope in scenario B in a real clinical setting during an RSI.

5.4 Paper IV

In scenario A, all anaesthesiologists secured an airway using each SAD well within the maximum time limit of 60 seconds. There were no significant differences in the time to completion using the i-gel™,
LTS-²™ or ETI devices. In scenario B (restricted access), all physicians secured the airway on the first attempt with the SADs but only 16 (80 %) successfully performed an ETI with either the Macintosh laryngoscope (n = 13, 65 %) or with digital technique (n = 3, 15 %). It took significantly longer to perform an ETI than to secure an airway with the SADs in this scenario (p < 0.001). No participants reported that they were comfortable with the ETI procedure under the limited access conditions, and only three stated that they were certain the ET was correctly placed in the trachea of the manikin. Two of these three physicians used the digital technique. For scenario B, all physicians secured an airway on their first attempt when using the SADs. When comparing the mean times for device placement, we observed a reduction in time for scenario B compared to scenario A of 2.2 seconds (p = 0.01) for the LTS-²™ and an increase in time for scenario B compared to scenario A of 2.4 seconds (p = 0.19) for the i-gel™.

5.5 Paper V

Data describing success rates, use of relevant accessories and rate and type of tracheal damage are listed in the paper. In the baseline test, no unsuccessful attempts with any technique were due to excessive time consumption. The single failure in performing BACT was due to the destruction of the cartilage and subsequent misplacement of the ET. The eight PCK failures were all due to placement of the tube in a false lumen caused by laceration of the posterior wall of the trachea or perforation through the tracheal wall. In the post-training test, all participants were successful with both techniques. Post-training tracheal laceration occurred in six (30 %) of the PCK procedures and in none of BACT procedures (p=0.028). The mean time consumption was reduced by 15.7 seconds (from 36.3 seconds to 20.6 seconds, p< 0.001) for PCK and by 7.8 seconds (from 44.9 seconds to 37.1 seconds, p=0.021) for BACT. In the post-training scenario, PCK was significantly faster in securing the airway than BACT (p<0.001). The median values for the self-evaluated confidence level at baseline and post-training tests increased from 4 to 8 for PCK and from 6.5 to 9.5 for BACT. When asked directly before each test and after each test, all participants answered that BACT was their preferred technique if they were able to choose between them in a clinical situation.
Part VI – Discussion

6.1 Paper I - On scene time (OST) in HEMS trauma missions and how need to perform RSI intubation influences the OST

Helicopter patient transport was established in a systematic manner in Norway in 1978 based upon similar services in Germany, Austria, and Switzerland. In the US, the use of helicopters for this purpose had been popularized some years earlier by the Maryland Institute for Emergency Medicine [135]. In both Europe and the US, the idea was that helicopter usage would result in the patient arriving faster at the hospital for definitive surgical treatment. This notion has been challenged, and conflicting results about the superiority of the helicopter vs. ground ambulance transport have been published [27, 108, 109, 136, 137]. There are several potential situations where helicopter transport may not be faster than ground transport. The distance between the scene of the incident and the receiving hospital and dispatch time for helicopters vs. ground units are important parameters. Both were recently addressed by Diaz et al., who showed that ground ambulance transport was faster than helicopter transport within 16 kilometres (10 miles) from the hospital [108]. When the distance was longer, helicopter transport was in general faster if dispatched simultaneously with the ground ambulance. However, if the dispatch was delayed until after ground personnel had assessed the patient, the helicopter became the fastest mode of transport only when the distance from the hospital was more than 83 kilometres (45 miles).

To ensure rapid help to patients needing interventions offered only by the air ambulance crew or to those needing swift transport to surgery, it is necessary to dispatch the helicopter simultaneously with the ground ambulance. The results described by Diaz et al. are in accordance with our own experience. In our service, simultaneous dispatch is therefore the rule when serious trauma is suspected. The price is, inevitably, overuse of the air ambulance. Other factors that can contribute to an increased time interval from alarm to patient arrival at the hospital are whether the helicopter can land at the scene and whether the HEMS crew encounters the patient in a ground ambulance en route from the scene of the accident to the trauma centre. Unpublished results from our own service show that transfer of a patient between a ground ambulance and a helicopter takes between 5-10 min, including necessary procedures like patient examination and exchange of monitoring equipment, as well as potential shut down and start up time of the helicopter. In 75 % of cases in the present study the helicopter landed less than 50 meters and in 18 % of cases between 50-200 meters from the site. The potential 5-10 min delay is thus avoided in the large majority of cases because ground ambulance transport is not needed.

This is a strong argument against the tradition in some HEMS services to operate with fixed, predetermined landing sites, requiring additional ground transport. This practice should be
discontinued to minimize the time from alarm to hospital arrival. In the US the ALS ground ambulance crews have more or less the same interventional skills as the US helicopter teams. For that reason, helicopter retrieval from the injury scene must be consistently faster than ground transport to have a potential impact on patient survival [138-142]. In most European HEMS, however, the helicopter crew concept includes a specially trained physician who can offer advanced interventions on the scene, delivered with quality that it is not realistic to be offered by paramedic ground ambulances. Induction of anaesthesia is one example. Hypotension and hypoxaemia both contribute to poorer outcome in trauma patients, particularly in TBI patients [70, 143, 144]. Pre-hospital RSI, if performed with the same level of quality as in-hospital, can effectively treat hypoxaemia, as shown by Newton et al. [59]. Of the 175 patients included in their study, all 22 patients who were hypoxaemic (defined as SpO₂ < 90 %) before RSI, arrived at hospital with increased SpO₂. This study was undertaken in London HEMS where the medical team consists of a physician experienced in field ETI and a flight paramedic. Other European studies including the present have shown that pre-hospital RSI can be performed with the same success rate in-hospital. In the study by Adnet et al., 685 (99.1 %) of 691 consecutive ETIs performed by physicians in the field were successful [111]. It was not necessary to establish any surgical airways. The frequency of difficult ETIs (11 %) in this French study was comparable to the incidence seen in US EDs, but not in US pre-hospital systems. Timmermann et al. performed a similar prospective study in a German EMS employing both car ambulances and helicopters [145]. During the 4-year study period, 1106 patients required ETI. Emergency physicians with at least 2 years experience from a department of anaesthesia and 1 year from an intensive care unit performed the ETIs. The overall failed intubation rate was 2 %.

In our own service, each physician performs annually on average 9 pre-hospital RSI and the same number of ETIs in OHCA patients. In addition, each physician performs a large number of ordinary drug-facilitated ETIs in the OR. In services like ours, the level of airway management offered in the field is similar to the hospital level, with the result that the patient is offered expert airway management sooner after the accident than would be the case if treatment on this level had been restricted to in-hospital patients. That said, it is still imperative to keep OST at a minimum to enable definitive surgical treatment as soon as possible. In the study presented here, we have shown that the OST is significantly higher in cases when an RSI is performed than when it is not performed (23 vs. 15 min, respectively). The OST in this study is defined as the time interval between landing and take off, meaning that activities like accessing and, when necessary, extricating the patient, performing primary survey and medical interventions, uploading the patient on a stretcher, carrying the patient to the helicopter, loading the patient into the vehicle, and performing checklists all are included in the OST. The increased OST of 8 min is on the same order of magnitude as found in other studies. The total pre-hospital time from alarm to patient arrival in the hospital was approximately 85 min on average. A Danish study from 2006 concluded that the OST increased by 8 min in cases with pre-hospital ETI performed by an anaesthesiologist [146]. In a study from Oregon, Cudnik et al. differentiated between RSI and conventional ETI and found that the OST increased by 11 and 5 min,
respectively, when the two procedures were performed by paramedics [147]. Carr et al. did a similar study in Mississippi to estimate the time cost of pre-hospital ETI and of intravenous access in trauma patients [106]. Although not clearly stated, it seems that it is the time cost of ETI that is reported. The time cost was estimated to be 3-4 min, depending on what additional procedures (e.g., airway management, suctioning, vascular access, CPR) were required. In this study, the frequency of difficult ETIs (15%) was higher than the incidence reported by Adnet et al. [111]. In contrast, in a study from San Diego, California, a total of 426 ETIs were reported, indicating that, on average, each paramedic in the service performed less than 1 RSI per 3 years [69]. The time spent on ETI cannot be separated from the time required for other pre-hospital procedures like positioning, suctioning, and establishing intravenous access, because the airway management never is performed in isolation.

Without RSI, it would have been necessary to secure the patients’ airways with other means such as a SAD. BVM ventilation is an option that often is difficult to perform adequately during transport. The airway is not secured with these techniques and SADs and BVM ventilation require that the patient does not have intact reflexes. ETI is thus a better alternative if the procedure can be performed quickly and correctly. Nonetheless, each and every case must be evaluated to determine the best alternative for the individual patient, ETI and increased OST, or alternative airway management with increased risk of airway compromise but possibly shorter OST. Factors that must be considered include airway compromise, other injuries sustained by the patient, distance to the trauma center, means of transport, and the experience of the pre-hospital care provider.

6.2 Paper II - The establishment of the frequency of desaturation, success rate and use of adjuvant clinical tools when performing rapid sequence intubation in the field

In a recent Danish prospective study, the first to comply with the Utstein style standard for reporting airway management data, 86% of out-of-hospitals ETIs by anaesthesiologists were successful on first attempt [39]. The overall incidence of complications was 22%, the incidence of hypotension 7% and hypoxia 5%. Multiple ETI attempts were associated with an increased overall incidence of complications.

To evaluate the quality of advanced airway management the anatomic features of the patient must be registered. Most used is the Cormack Lehane grading were difficult intubation has been classified into four grades, according to the view obtainable at laryngoscopy [56]. This corresponds somewhat to the Mallampati score that is frequently used in pre-anaesthetic evaluations [148].

Hypoxaemia contributes to poor outcome after injury, especially in head-injured patients [149]. It is also imperative to avoid hypoxaemia in non-traumatic cases such as spontaneous subarachnoidal haemorrhage and circulatory disorders. Few reports focus on advanced pre-hospital airway management in patients experiencing the latter kind of disorders [150]. Recent reports indicate that
hypoxaemia occurs with relatively high frequency during pre-hospital RSI in trauma patients. Dunford et al. [151] in San Diego found that 57% of the patients in their study on pre-hospital airway management in severe head injury had an episode of hypoxaemia during paramedic-performed RSI. The hypoxaemic event lasted longer than 3 minutes in almost half of the cases. This study included adult patients with GCS between 3-8 with failed non–drug assisted ETI attempts. This practice is in sharp contrast with our standards, where ETI without drugs almost exclusively is used in patients with cardiac arrest. A recent report from London HEMS showed that 18% of their RSI patients experienced hypoxaemia during the procedure [59]. This service only attends trauma cases, and the team physician, having a background in emergency medicine, anaesthesia, or critical care, performs the RSIs. As in our service, drug-assisted intubation is mandatory in the London HEMS. In RSIs performed in the ED, mostly on non-trauma cases, 19% developed hypoxaemia defined as SpO2 below 90% during the RSI [113].

In the present study, the definition of hypoxaemia was the same as in the London HEMS report and as the San Diego and London studies with oxygen saturation data objectively recorded to avoid recording or recall bias. The 11% hypoxaemia rate in both trauma and medical patients during pre-hospital RSIs was lower than that in the aforementioned studies. However, there were incomplete recordings in 21 missions, and it cannot be ruled out that these cases represented a unique subgroup. Our calculated hypoxaemia incidence may therefore be an underestimation. Another possibility is that our case mix, with a high proportion of medical patients, can explain the differences.

It is reasonable to assume that the level of training of the intubator will influence the success rate [47]. In the San Diego study, paramedics with 7 hours of formal instruction in RSI and no expertise in anaesthesia performed the procedure. The complication rate was so high that the study was prematurely stopped. London HEMS physicians have clinical backgrounds in emergency medicine, anaesthesia, or critical care medicine. In our service, all HEMS physicians are board certified anaesthesiologists, spending 80% of their working hours in the field and the remaining time at the department of anaesthesiology as senior consultants. They all have extensive pre-hospital experience (median, 14 years; range, 4-29 years), which may explain the lower desaturation rates encountered in the present study. In the study from London HEMS, 20 physicians performed 244 RSIs during the study period, resulting in an average of 12 RSIs per physician per year. In our study, 14 doctors shared the 122 pre-hospital RSIs that were performed, giving an average of 9 annual pre-hospital RSIs per physician. Each HEMS physician performed on average the same number of pre-hospital ETIs on patients with cardiac arrest. In addition, all physicians performed a number of ETIs in the ED and in the OR during the study period. These figures suggest that HEMS physicians in our base maintain a higher intubation rate than what seems to be the case in London HEMS. According to Dunford et al., 484 paramedics shared a total of 426 RSIs during the 3 ½ years that the San Diego Paramedic RSI Study lasted. This indicates that each paramedic on average performed less than 1 RSI per 3 years. Common sense and human nature dictate that the more often an intubator performs the procedure,
the higher the success rate will be. The high annual number of pre-hospital and in-hospital ETIs performed by the physicians in our HEMS service may contribute to our low complication rate.

Physicians perform most of the pre-hospital RSIs in many European countries. In a French multicenter study, 99% of the pre-hospital ETIs were successful [111]. Timmermann et al. [145] reported a pre-hospital RSI success rate of 96.1% for trauma patients in a German study [145]. Similar results have been reported from the London HEMS [59, 113]. Thus, our 99% success rate of pre-hospital RSI is comparable with the reported rates from other European physician-based emergency medical services.

Our results indicate that a small group of critically injured or ill patients, with SpO₂ below 90% before the RSI, runs a high risk of becoming even more hypoxaemic during the procedure. In this material, inadequate preoxygenation seems to be the only variable correlated with hypoxaemia. We had expected that anatomical and technical difficulties encountered in connection with ETI would result in a higher incidence of hypoxaemia and hypotension. Our data do not, however, support this assumption. Technical difficulties increase the duration of the procedure, but not to the extent of causing hypoxaemia.

6.3 Paper III - Feasibility of video laryngoscopy in simulated entrapped patient scenarios

The patient in need of a secure airway in the field can often be evacuated to more hospitable surroundings in the immediate vicinity, providing more optimal conditions for ETI and reducing the inherent risk of the procedure to a minimum. Under such conditions, pre-hospital ETI by experienced physicians can be performed with a similar success rate as in the hospital [111, 145]. The entrapped or physically confined patient, however, occasionally demonstrates such respiratory distress that the airway needs securing before extrication or evacuation is possible. SADs may be sufficient for temporarily maintaining the airway in such settings, but haemorrhaging, vomiting or other circumstances may dictate ETI as the only acceptable alternative. In such instances, conventional ETI using a Macintosh laryngoscope may not be a satisfactory – or a feasible – solution, especially when the patient is in a location where access to the patient’s airway from the cephalad end is not possible. Drug-assisted VL may be a safe alternative under such circumstances, releasing the intubator from the boundaries of traditional positioning for laryngoscopy.

Few studies describe airway management in entrapped patients. To the authors’ knowledge, only manikin studies and some case studies have been published on the subject. Hoyle et al. compared the ETC, LMA and ETI in three pre-hospital airway scenarios. One of their scenarios was very similar to scenario B in the present study. The authors found that ETI resulted in a significantly longer time for ventilation than when the LMA was used, independent of whether airway management was performed by paramedics or physicians. The success rate for ETI with the Macintosh laryngoscope in
our scenario B was only 50 %. Unfortunately, Hoyle et al. did not report success rates for the various techniques included in their study, making a comparison with our study impossible. Hulme and Perkins have published a series of 15 cases, where the LMA was used to secure the airways in patients in whom access to their airways was limited [152]. In 11 of these cases, patient positioning precluded traditional attempts at ETI. In the majority of these cases, the LMA performed adequately, and subsequent pre-hospital ETI after extrication was not performed. This report indicates, however, that the LMA is occasionally not sufficient for securing the patient’s airway, indicating a necessity for ETI.

This study has several limitations. It is always difficult to predict to which extent the results from a manikin study may be transferred to a clinical setting. However, due to ethical and methodological reasons, it would be very difficult to study airway management in real patients in the clinical situations simulated in this study. A well-designed manikin study is a necessary and an acceptable surrogate for the ideal, randomized clinical study. In order to mimic a clinical setting, where the patient cannot be accessed from a cephalad direction, a model was developed with a Laerdal SimMan® strapped supine on an ambulance stretcher, with the head abutting a wall, rendering it impossible to secure the manikin’s airway from the traditional cephalad position. We believe that this model is representative of the majority of entrapped patients, ruling out normal access for rescuers to the patient’s head and airway, even though there are situations where access may be easier or worse than described in this model. Half of the anaesthetists taking part in the study managed to secure the airway of the manikin from the front standing on the manikin’s left-hand side using a Macintosh laryngoscope (inverse intubation). Nonetheless, all participants stated that inverse intubation would not have been an option for them during a real-life situation of drug-induced RSI, as the inherent risk of the procedure was considered to be too high. The consequences for the patient would have been disastrous if ventilation was not possible with alternative methods in case of a failed ETI attempt. With the GlideScope Ranger®, on the other hand, the anaesthetists felt that the probability of a successful ETI was sufficiently high to warrant RSI with appropriate drugs given before the intubation procedure in selected cases. The 100 % success rate in scenario B supports this notion. It is a limitation that only eight anaesthetists participated in the study, making the investigation too small to detect minor differences between the methods. There were no significant differences in the time spent during intubation attempts with the Macintosh laryngoscope and the GlideScope Ranger® video laryngoscope. It must be taken into account that while all the participants were very experienced with the standard ETI performed using a Macintosh laryngoscope, none had any clinical experience using GlideScope Ranger®. It is therefore not unreasonable to assume that the difference in the time spent between the two intubation techniques will decrease as the involved anaesthetists gain more practice with the GlideScope Ranger® in various settings. Little is known from the pre-hospital setting about possible injuries to the cervical spine of a traumatized patient. Consequently, the application of a rigid cervical collar and neutral positioning of the head and neck is considered mandatory. VL may be an interesting alternative for trauma patients with
normal access to the airways because AN ETI can be performed with less manipulation of the neck than when the ETI is performed using a Macintosh laryngoscope [153].

6.4 paper IV - The comparison of ETI, i-gel™ and LTS-2 in simulated advanced airway management and in simulated entrapment of the patient

6.4.1 What device to use?

Our results show that airway management with i-gel™, LTSII™ and ETI in scenarios with optimal access to the simulated patient (scenario A) is fast with high success rates with all devices when performed by experienced anaesthesiologists. The difference in time spent between the devices is probably of no clinical significance. Thus, with optimal access to the patient, ETI is the method of choice, because it results in a cuffed ET in the trachea. In a scenario of restricted access to the manikin head (scenario B), however, our study indicates that ETI is potentially unsafe with four of 20 attempts not resulting in a secured airway. ETI was also a more time-consuming technique under these conditions, although a 16 second increase may not be clinically significant. Based on the results from scenario B, one could argue that SADs are superior to ETI when the access to the patient’s airway is restricted.

Under ideal conditions, experienced physicians can perform ETI pre-hospitaly with similar success rates as when performed in hospital [58, 111, 145]. Usually, the patient can be evacuated onto an ambulance stretcher with adjustable height to improve conditions prior to definitive airway management. However, entrapped patients and patients located in confined spaces may occasionally be in such respiratory distress that a secure airway and mechanical ventilation prior to extrication or transport are required. In a multi-centre study from German HEMS, by Helm et al., limited access to the patient was found in 20 % of patients upon arrival and in almost 10 % of patients at the time of the first ETI attempt [1]. This makes it relevant to study if SADs provide a safer way to secure the airway in cases of restricted access.

6.4.2 The postulated training effect when using a fixed airway simulator for evaluation of airway management techniques

Recent years have provided numerous studies on equipment and techniques evaluated by use in manikins – a trend that has been strongly criticized [119]. We believe manikin studies are useful evaluating techniques where tissue quality is of little importance - as in the evaluation of video laryngoscopes and fibroptic scopes [154-156]. In addition, in studies like the present of airway management in patients where the access is restricted, manikins are needed for ethical reasons. As mentioned below, a manikin-based study must be well designed to become an acceptable surrogate for real patients.
One previous study, and our early testing prior to this study, indicated that there may be a training effect when the same airway simulator is used for a limited number of airway manoeuvres [157]. To evaluate this possible effect we decided not to randomize the sequence of techniques performed in the two different scenarios. In addition, scenario B was constructed so that a significant increase in time spending could be anticipated if there was no training effect. The finding of a small significant reduction in the mean time spent on securing the airway of the manikin with LTS-2 between scenario A and B, despite the much higher degree of difficulty in scenario B, support our assumption of a substantial training effect. It is possible that participants remembered the anatomy and tissue-quality of the manikins in scenario A, so that repeat testing in scenario B resulted in faster completion times. It may also, however, be that the increased familiarity with the LTS-2 is the main reason. Some studies have evaluated the role of different airway trainers when teaching how to place SADs [158, 159]. One recent study compared the use of fresh frozen cadavers with selected airway simulators to evaluate which simulator mimicked the quality of a real ETI [160]. None of these studies, however, addressed the implications of a fixed anatomical condition. The need to employ two different manikins is a significant limitation of this study. However, we believe that the limitations of the study would have been more significant if only one manikin had been used, because we found no manikin suitable for both types of simulated airway intervention. The arrangements of the manikins were made as similar as possible.

6.5 Paper V - The difference in performance at baseline level and after training with percutaneous and surgical techniques for cricothyrotomy in a cadaveric porcine airway model

The model based on adult pig’s larynxes has previously been shown to be feasible for skill training in cricothyrotomy and for evaluation of new techniques [161, 162].

The PCK baseline test resulted in a success rate of only 60 %. All failures were due to placement of the tube in a false lumen or through the posterior tracheal wall. The success rate and laceration rate of the posterior tracheal wall was comparable to data from other studies in which inexperienced participants performed the procedure [162, 163]. Small linear lacerations may be of no clinical importance while major lacerations with penetration through the tracheal wall may be catastrophic.

Our results contrast with the only report of PCK use in vivo that we have identified in which time to successful insertion was 84 and 110 seconds in the two procedures that were reported [164]. The time to successful insertion using PCK in our study may be influenced both by our design and by the anatomic model. Participants were standing ready next to the model with all equipment available on a table when time recording started. The recording was stopped when the participant said “finished” and the tube was in place and cuffed but prior to connecting a self-inflatable bag. A realistic preparation of equipment would likely increase the measured time to successful insertion. A lack of
bleeding and a thinner soft tissue than in real patients may also influence the time to successful insertion in this study. Another factor may be the general clinical experience of the participants.

Although personnel, equipment and lack of direct light were arranged similar to pre-hospital daylight conditions, one may argue that the comfort of the lab environment may improve performance. For instance, the mental stress of an unanticipated CICV situation cannot be simulated. Another limitation may be the homogeneity of the population of participants of the study. The results may not be directly applicable to services and clinical situations in which other types of health care providers perform cricothyrotomy.
Part VII - Conclusions

7.1 On scene time in HEMS trauma missions

The helicopters can land close to the scene in the majority of trauma cases avoiding increased pre-hospital time due to ground ambulance transport between the scene and the landing site. It is our belief that RSI is a vital skill that can be performed pre-hospitally with acceptable risk when performed by an experienced health care professional who performs the procedure on a frequent basis in both pre-hospital and hospital settings. As RSI increases the OST, each case must be evaluated individually to determine whether airway management with other devices will be sufficient.

7.2 Incidence of desaturation

This study demonstrates that pre-hospital RSI performed by an anaesthesiologist working in this type of HEMS is a safe procedure for trauma and medical emergency patients, with an incidence of adverse affects comparable to in-hospital findings. Inadequate preoxygenation and initial $\text{SpO}_2$ values below 90% increase the risk for severe hypoxaemic episodes during the procedure.

7.3 Feasability of video laryngoscopes

The Glidescope Ranger® video laryngoscope was chosen for this study because the screen is detached from the laryngoscope handle, enabling the person using the device to intubate from positions deviating from the standard position at the head of the patient. Further studies comparing this with other video laryngoscopes should be performed to establish whether or not there are clinically important differences between the various devices in the described setting. Financial considerations must also be taken into account. In situations where traditional laryngoscopy is not feasible, it would be of interest to investigate whether more affordable video laryngoscopes may be used.

7.4 Comparison of Macintosh laryngoscope, i-gel™ and LTS-2

Airway management in cases of restricted patient access is not emphasized in current airway management guidelines [42, 44, 165]. Based on use of a manikin head, this study demonstrates that ETI is potentially unsafe in a scenario of restricted access to a patient. SADs seem superior. No clinically important difference was found between the two devices studied.
Since pre-hospital airway management devices largely evolve from the field of anaesthesia, much of the medical literature regarding new devices focuses on the OR. With the many obvious practical and clinical differences between these clinical settings, further studies in the pre-hospital environment are needed, specifically trials correlating neurologic outcome to choice of SAD. In the past, trials focused mainly on effectiveness and safety of ventilation with a SAD. Most current literature describes the speed and ease of insertion over ETI. Future studies must focus on determining clinically significant harms or benefits of using SADs in a pre-hospital setting during specific clinical situations at specific times during resuscitation in both adults and children.

7.5 Training effect in manikin studies

Our study indicates that a substantial training effect exists after just two maneuvers with an airway simulator and two different airway devices. This effect is likely due to the fixed anatomy and material of the manikins. It must be considered when evaluating different airway management techniques and airway devices in future studies.

7.6 Difference between BACT and PCK

Testing base-line PCK skills of pre-hospital anaesthesiologists revealed low confidence, sub-optimal performance, a failure rate of 40 % and a high tracheal injury rate of 60 %. The BACT technique at the base-line level demonstrated a significantly higher success rate (95 %) and no tracheal damage. After the intensive training package, a one hundred percent success rate was achieved with both techniques, and a reduction in time to successful insertion was found for both techniques. The mean time used to secure the porcine airway with PCK was significantly lower than with BACT and may be of clinical importance. The clinicians rated a higher confidence in BACT in all phases of this study. The difference, however, was reduced after completion of the training. Based on our findings, it is likely that adequate PCK performance can only be achieved if training is performed on a regular basis. If a medical system is not able to provide its physicians with sufficient training, BACT is the better choice.
Errata

In papers I, II and IV Wilcoxon’s signed ranks test was erroneously named Wilcoxon’s paired t-test.
References


