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In-hospital bed occupancy and the emergency department

effects on decisions about the level of care

Mathias Blom MD



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DOCTORAL DISSERTATION

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To be defended in Segerfalk Lecture hall, June 12 2015, 09:00.

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In-hospital bed occupancy and the Emergency Department – effects on decisions about the level of care	
<p>Background: Emergency Department (ED) overcrowding occurs when the need for ED services outstrips available resources. Causes have been divided into input, throughput, and output factors, of which the last appear to be the most influential. Unavailability of inpatient beds (so-called “access block,” or “hospital crowding”) impairs ED output and is associated with increased waiting times in the ED, especially for patients awaiting hospital admission (“boarding”). Access block has also been suspected to induce an admission-bias, causing only the sickest patients to be admitted to hospital when hospital beds are scarce.</p> <p>The aim of this thesis was to evaluate whether access block affected the prioritization of the level of care in ED patients so that patients were less likely to be admitted to a hospital bed at times of access block than otherwise. Part V addressed whether more patients were triaged out of the ED at times of access block.</p> <p>Methods: In Part I, the proportion of hospital admissions among 118,668 visits to the ED, at a 420-bed emergency hospital in Region Skåne, Sweden, was compared across different levels of access block (measured as strata of in-hospital bed occupancy). Multivariate models were constructed to adjust for the effects of known confounders. In Part II, the appropriateness of ED discharges was addressed by comparing the proportion of unplanned 72h revisits to the ED across different levels of access block, for the 81,878 cases treated and released from the ED at index. In Part III, the outcomes evaluated in Parts I and II were addressed for 19,620 ED visits due to acute abdominal pain. Part IV was performed analogously to Part III, but for 12,223 ED visits due to chest pain. In Part V, the permeability of an ED front-end facility that triages patients of perceived low acuity out of the ED was compared across different levels of access block, for 37,129 visits to the facility.</p> <p>Results: In Part I, a negative association between access block and the probability of inpatient admission was observed (OR 0.67–0.81 at occupancy >105%, compared to at occupancy <95%), implying that patients were less likely to be admitted to the hospital at times of access block. Part II revealed no association between access block and the 72h revisit rate. The association detected in Part I remained for the study populations addressed in Parts III/IV. No association between access block and the 72h revisit rate was observed in patients with acute abdominal pain, but a negative association between the two was observed in patients with chest pain. ED length of stay in patients who were treated and released from the ED increased at times of access block, in Parts III/IV.</p> <p>Conclusion: ED patients were less likely to be admitted to a hospital bed at times of access block than otherwise, at the study site. The lack of an association with the 72h revisit rate could be interpreted as that the practice is safe, but since it fails to take into account rare, but fatal, outcomes such as mortality, future studies should address more granular patient outcomes and specific subgroups. Cost-effectiveness analysis could help to evaluate the viability of managing certain conditions in the ED as compared to in inpatient wards.</p>	
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“Gratitude is not only the greatest of virtues, but the parent of all the others.”

Marcus Tullius Cicero

Original papers

The thesis is based on the following papers, which will be referred to by their Roman numerals.

- I. Blom MC, Jonsson F, Landin-Olsson M, Ivarsson K. The probability of patients being admitted from the emergency department is negatively correlated to in-hospital bed occupancy – a registry study. *Int J Emerg Med.* 2014;7:8.
- II. Blom MC, Jonsson F, Landin-Olsson M, Ivarsson K. Associations between in-hospital bed occupancy and unplanned 72-h revisits to the emergency department: a register study. *Int J Emerg Med.* 2014;7:25.
- III. Patients presenting at the emergency department with acute abdominal pain are less likely to be admitted to inpatient wards during hospital crowding: a registry study. Blom MC, Landin-Olsson M, Lindsten M, Jonsson F, Ivarsson K. In manuscript.
- IV. Patients who present at the emergency department with chest pain are less likely to be admitted to a hospital bed at times of access block - a registry study. Blom MC, Landin-Olsson M, Jonsson F, Ivarsson K. In manuscript.
- V. Patients are not increasingly denied admission to the emergency department at times of access block - a retrospective cohort study. Blom MC, Erwander K, Gustafsson L, Landin-Olsson M, Jonsson F, Ivarsson K. In manuscript.

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Abbreviations

ACEP – the American College of Emergency Physicians

ACG – adjusted care groups

ACS – acute coronary syndrome

ADAPT – adaptive process triage

AHA – the American Hospital Association

AHRQ – the Agency for Healthcare Research and Quality

AMI – acute myocardial infarction

APHA – the American Public Health Association

ASPE – the Assistant Secretary for Planning and Evaluation

ACS – acute coronary syndrome

CABG – coronary artery bypass surgery

CADTH – Canadian Agency for Drugs and Technologies in Health

CI – confidence interval

CNI – care need index

COPD – chronic obstructive pulmonary disease

CT – computed tomography

DAG – directed acyclic graph

DRG – diagnosis related groups

ED – emergency department

EDCS – the emergency department crowding scale

EDLOS – emergency department length of stay

EDOU – emergency department observation unit

EDWIN – the emergency department work index

EM – emergency medicine (medical specialty)

EMTALA – emergency medical treatment and labor act
ESBL – extended spectrum beta lactamase
ESI – Emergency Severity Index
ESS – emergency symptoms and signs
GCS – Glasgow coma scale
HIAA – the Health Insurance Association of America
HMFP – Harvard Medical Faculty Physicians
HRSA – the Health Resources and Services Administration
ICU – intensive care unit
IOM – the Institute of Medicine of the National Academies
IPLOS – inpatient length of stay
IVO – the health and social care inspectorate
LAMA – leaving against medical advice
LWBS – leaving without being seen
METTS – medical emergency triage and treatment system
MRSA – methicillin-resistant Staphylococcus aureus
NCHS – the National Center for Health Statistics
NEDOCS – the National Emergency Department Overcrowding Study
NEDSS – the National emergency department safety study
NGK – Nagelkerke's R^2
NHAMCS – the National Hospital Ambulatory Medical Care Survey
NHS – the National Health Service
NIS – the nationwide inpatient sample
NRC – the National Research Council
NSTEMI – non-ST elevation myocardial infarction
OR – odds ratio
PCI – percutaneous coronary intervention
PE – pulmonary embolism
PME – preventable medical error
RCT – randomized controlled trial

READI – the real-time emergency analysis of demand indicators
RETTS[®] – Rapid emergency triage and treatment system
ROC – receiver operating characteristic
RR – relative risk
SAEM – the Society for Academic Emergency Medicine
SKL – the Swedish Association of Local Authorities and Regions
SPC – statistical process control
STEMI – ST-elevation myocardial infarction
SUS – Skåne university hospital
SWESEM – the Swedish Society for Emergency Medicine
WHO – the World Health Organization

Introduction

Emergency Department overcrowding

The issue of Emergency Department (ED) overcrowding is not a modern phenomenon. In the US, ED overcrowding was put on the national research agenda almost 50 years ago. In 1966 the US National Research Council (NRC) described a crisis in the US emergency care and response system in the report “Accidental Death and Disability: The Neglected Disease of Modern Society” (1). The NRC stated that “Emergency departments of hospitals are overcrowded, some are archaic, and there are no systematic surveys on which to base requirements for space, equipment, or staffing for present, let alone future, needs.”

In an attempt to develop new solutions to the persisting problem, the American College of Emergency Physicians (ACEP) invited several key stakeholders to the National Congress on the Health Care Safety Net in 2000. Amongst them were the American Hospital Association (AHA), the American Public Health Association (APHA), the Health Insurance Association of America (HIAA), Families USA, the Institute of Medicine (IOM), and various governmental representatives (2). The 2001 consensus conference on the Safety Net was hosted by the Society for Academic Emergency Medicine (SAEM) in the following year. This conference brought together three agencies involved in implementing the IOM safety net report: the Agency for Healthcare Research and Quality (AHRQ), Health Resources and Services Administration (HRSA), and the Assistant Secretary for Planning and Evaluation (ASPE) (3). Around the same time, the ACEP hosted roundtable discussions titled “Meeting the Challenges of Emergency Department Overcrowding/Boarding”(2). The position of ED overcrowding on the US research agenda was additionally reinforced in the last decade, after the release of three comprehensive reports by the IOM. Their titles were “Hospital-Based Emergency Care: At the Breaking Point”, “Emergency Care for Children: Growing Pains”, and “Emergency Medical Services: At the Crossroads” (4-6). The overall conclusion was harsh, stating that ED overcrowding was part of a “brewing national crisis” (6).

A poll conducted by the ACEP in the mid 2000’s revealed that about 70% of Americans believed that US EDs were approaching a “crisis due to overcrowding” (2). A more recent study of nearly 4,000 American hospital EDs showed that

nearly half reported “operating at or above capacity” (7). In a pilot study addressing the point prevalence of ED overcrowding, Schneider (2003) described that about 40% of ED directors experienced ED overcrowding on a daily basis and that nearly all of them considered it to be a problem (8). The US General Accounting Office has highlighted the issue both in a 2009 and a 2003 report (9, 10).

Even though the US research community is the most active in researching ED overcrowding (11) and in advocating their points toward the decision makers, the phenomenon is by no means confined to the US healthcare system (12). In 2012, a group of researchers described the emergency care systems and status of ED overcrowding in 15 countries outside the US. They report that ED overcrowding is a substantial problem in several countries, including Australia, Canada, France, India, Iran, Italy, Saudi Arabia, and Spain. Long wait times in the ED and the boarding of patients awaiting admission to an inpatient bed was prevalent in additional countries, also where a universal publicly funded healthcare system was present (11). The Scandinavian countries, and Sweden in particular, were put forward as examples of countries experiencing no major problems. However, waiting times and overcrowding within the Swedish emergency care system has received much attention since.

A milestone in regard to Swedish ED overcrowding was the report published by the Swedish National Board of Health and Welfare in 2011, with title “Väntetider vid sjukhusbundna akutmottagningar”. The report was published in response to a governmental assignment requesting the board to describe waiting times at hospital EDs and the conditions for measuring and reporting them in the future. The report states that the Swedish healthcare system has been exceedingly divided into unplanned (acute) and planned care processes during the latest decades, and that the number of emergency departments open around the clock has decreased as a consequence (13). One of the government’s main incentives for giving the assignment to the National Board of Health and Welfare was the need for a better description of the emergency care system in terms of patients, processes, and the work conducted. Contrary to popular belief, the conditions for describing the Swedish emergency care system are limited, as the national patient registry does not permit separate identification of patients entering the inpatient healthcare system through the EDs. Apart from obstructing the description of processes and outcomes for the ED cohort, the organization of the registry also results in that the number of annual ED visits in Sweden cannot be measured appropriately. A rough estimation made by the board was 2.5 million visits in 2010 (13).

In response to the report, the board received another assignment in March 2012. The main essence of this new assignment was to improve the national level follow-up of the accessibility to healthcare in Sweden and to develop a system for following patients’ individual paths through the healthcare system. Another part of the assignment was to describe waiting times from different perspectives (e.g., sex,

age, diagnosis), to monitor accessibility to acute as well as elective care, and to suggest quality indicators aimed at capturing patient safety and patient experience in emergency care delivery (14). The final report on quality indicators for emergency care was delivered in December 2013 and recommended the following 7 outcome measures be appointed quality indicators for Swedish emergency care delivery (14):

- ED length of stay (EDLOS) (median)
- Time to first assessment by a physician for patients presenting in the ED (median)
- The proportion of patients discharged from the ED that return within 72 hours
- The fraction of patients who leave on their own behalf, after physician assessment
- The proportion of patients who report that they received information about anticipated waiting times during their stay in the ED
- The proportion of patients who perceive the quality of care in the ED as good
- The proportion of ED patients who perceive that analgesia was adequate

The latter three indicators are to be collected from the national patient survey (“nationella patientenkäten”). The former four are to be reported to the patient register monthly by each Swedish hospital-affiliated ED. The Board also expressed its ambitions to collaborate with the Swedish Association of Local Authorities and Regions (SKL) and the Swedish Society for Emergency Medicine (SWESEM) to develop a foundation for evaluation and quality assurance in the Swedish emergency care delivery system. The reporting of waiting times has also been tied to governmental reimbursements through “Kömiljarden” (15).

The National Board of Health and Welfare reported an increase in median ED length of stay (EDLOS) at Swedish emergency departments, from 2 hours 28 minutes in 2010 to 2 hour and 46 minutes in 2013. The variation ranged from 1 hour 48 minutes at the ED at Avesta hospital to 4 hours 20 minutes at the ED of Sahlgrenska University hospital. The median wait for physician assessment ranged from 20 minutes at the EDs of Piteå and Bollnäs hospitals to 1 hour and 53 minutes at Sahlgrenska University hospital (14).

One forum for discussion and feedback to the board’s project has been the partially government funded initiative “Akut förbättring”, which was conducted in 2012-2013 and involved 27 of the 70 hospitals providing emergency care around the clock at the time. The final report concludes that almost all Swedish hospital

EDs have experienced increased volumes of ED visits during the last decade, and that the increase is ongoing. Many participants perceive long waiting times in the ED as a problem (16).

Similarly, in 2012, the National Center for Health Statistics (NCHS) reported that the median wait time to see a provider in US EDs increased from 27 to 33 minutes between 2003 and 2009. EDs in urban areas and high-volume EDs experienced longer waits (17). The percentage increase in waits to see a physician was reported 4.1% per year between 1997 and 2004 in a study of the National Hospital Ambulatory Medical Care Survey (NHAMCS) dataset. The increase was greater (11.2%) for patients with acute myocardial infarction (AMI) (18).

Definition

Most ED practitioners would be able to identify ED overcrowding instantly, but the definition has been subject to some variation. One definition put forward by the ACEP in 2004 reads that ED overcrowding is (19):

A situation in which the identified need for emergency services outstrips available resources in the ED. This situation occurs in hospital EDs when there are more patients than staffed ED treatment beds and wait times exceed a reasonable period. Crowding typically involves patients being monitored in non-treatment areas (e.g., hallways) and awaiting ED treatment beds or inpatient beds. Crowding may also involve an inability to appropriately triage patients, with large numbers of patients in the ED waiting area of any triage assessment category.

A shorter definition suggested by former ACEP president, Dr. Frederick Blum (2), reads that ED overcrowding "exists when the institutional resources available are insufficient to meet the basic service needs of emergency patients".

In a 2008 report the ACEP taskforce on boarding (20) stated that ED overcrowding "exists when there is no space left to meet the timely needs of the next patient who needs emergency care" and that "if the care of an urgent problem is delayed due to congestion, then crowding exists".

Although the definitions reported above are fairly coherent in that they all contain the element of demand outstripping supply, a relative inconsistency in the definition of ED overcrowding was highlighted as a problem in a review article from 2004. The conclusion of the article was that the definitions encountered "varied widely in content and focus, including ED, hospital, or external (nonhospital) factors" (21). After reviewing the literature, my impression is that the definition has converged on that proposed by the ACEP in 2008, but that the main problem is that the measurement of ED overcrowding differs substantially between scientific studies. This is troublesome, as an incoherent definition of the exposure inevitably affects the generalizability of results produced by the research

community. This will be more elaborated in the section: “The international research agenda”. As a final remark, the terms “ED overcrowding” and “ED crowding” are used rather interchangeably in the literature. Some prefer “ED crowding” (22, 23), while others prefer “ED overcrowding” (12). I will use “ED overcrowding” for the purposes of this essay.

Conceptual model

Most texts on the topic agree that ED overcrowding does not reflect dysfunction in the ED in isolation, but reflects a more general mismatch between supply and demand in the healthcare system (10-13, 20, 22, 24-27). The causes of ED overcrowding are often discussed in the context of the conceptual model proposed by Brent Asplin in 2003 (24). The fundamental concepts of the model are drawn from queuing theory (which will be elaborated on in the section “A systems perspective on ED overcrowding”) and divide causes of ED overcrowding into input-, throughput-, and output factors. Input factors regulate patient flow into the ED. Throughput factors regulate patient flow through the ED; consequently, output factors regulate patient flow out of the ED. This conceptual model is still used as the main framework for discussing ED overcrowding (12, 28). Shortly after the publication of Asplins original article, the ACEP suggested an additional separation of causes on the micro and the macro level, where the micro level constitutes the factors covered by Asplins model and the macro level constitutes “forces of the national and regional levels that drive ED crowding, such as the federal and state government health programs“ (19). Asplins conceptual model, together with the most important causes, are reported in Figure 1. Specific causes are elaborated in the “Causes” section.

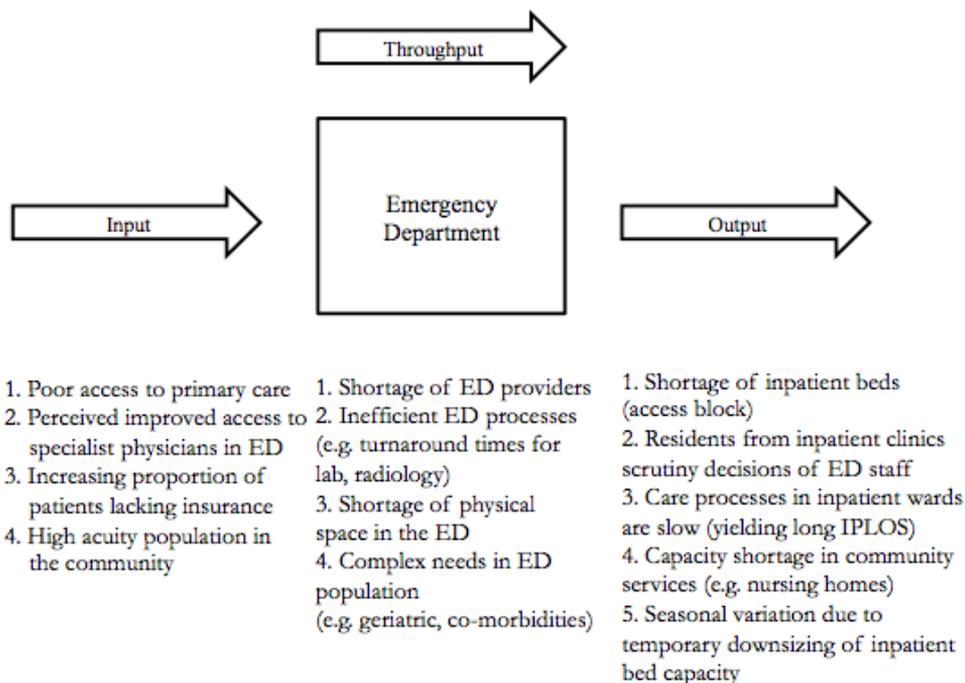


Figure 1. Conceptual model of Emergency Department overcrowding

Effects of ED overcrowding

The IOM expressed its concerns about the impact of ED overcrowding on the quality of care by stating that “demands on the system can degrade the quality of emergency care and hinder the ability to provide urgent and lifesaving care to seriously ill and injured patients wherever and whenever they need it”(6).

In a review article, Hoot (2008) reported that the most commonly studied effects of overcrowding are “patient mortality, transport delays, treatment delays, ambulance diversion, patient elopement, and financial effects” (26). The former president of the American College of Emergency Physicians cited the paper titled “Emergency Department Crowding and Thrombolysis Delays in Acute Myocardial Infarction” by Schull (2004) (29) as one of the first pieces of evidence showing that ED overcrowding leads to impaired quality of care (29). Endpoints addressed in the ED overcrowding literature often concern mortality, while some studies also report quality-of-life outcomes. Additional studies primarily address process outcomes; e.g., timeliness of time-sensitive interventions, adherence to protocols, and medical errors. Concerns about consequences for the humans in the system are expressed by the IOM in their 2006 report (6) as follows: “overcrowding induces stress in providers and patients, and can lead to errors and impaired overall quality of care”. Provider stress and burnout has been supported

by an association between ED overcrowding and emotional exhaustion in staff (30, 31).

A survey of 2,507 US emergency physicians, using an electronically collected questionnaire of 16 patient safety concerns on a 5-point Likert scale, revealed that ED overcrowding was the greatest patient-safety concern for suburban (mean 4.3) as well as urban (mean 4.5) ED physicians, while being in the seventh place for rural ED physicians (mean 3.5) (32).

Even though the effects of ED overcrowding were not addressed explicitly, a 2007 report of 79 legal claims due to diagnoses missed in the ED revealed that factors that are potentially affected by ED overcrowding were frequently cited as causes. For example, cognitive factors contributed in 96% of the cases, lack of appropriate supervision in 30%, inadequate handoffs in 24% and excessive workload in 23% (33).

In a chapter of a recently published textbook on ED management and leadership, Anantharaman and Seth (2015) divide the most frequently cited effects of ED overcrowding into effects on the patient and organizational levels and into effects on staff (12):

Patient-level effects of ED overcrowding

- Leaving the ED without being seen
- Prolonged boarding of critically ill patients
- Longer waiting times to see a physician, results in impaired timeliness of care

Organization-level effects of ED overcrowding

- Ambulance diversions
- Increased EDLOS
- Prolonged inpatient length of stay (IPLOS)
- Increased mortality
- Impaired quality of care (measured as errors, adherence to guidelines)

Consequences of ED overcrowding for staff

- Provider stress and burnout
- Impaired provider recruitment and retention
- Detrimental effects to teaching and research
- Increased frequency of confrontations between staff, patients, and patients' families

- Increased inter-disciplinary confrontations (i.e., ED vs. inpatient clinics)

The evidence base for some specific consequences of ED overcrowding are elaborated below:

Several studies address the association between ED overcrowding and mortality. For example, an analysis of nearly a million admissions from the ED across 187 hospitals in California revealed a 5% increased odds of inpatient death on days experiencing high ED overcrowding. Quantified, these numbers amounted to 300 inpatient deaths in 2007 (34). A retrospective review of data from 34 EDs in Korea from 2006-2008, comprising 125,031 pediatric patients admitted to hospital, revealed that patients presenting at the ED when it was overcrowded suffered higher inpatient mortality than other patients with a relative risk (RR) of 1.019-1.558 (95% confidence interval, CI) (35). Another retrospective review of more than 20 million ED visits in Ontario from 2003-2007 revealed an association between presenting on a shift with long waiting times and death within 7 days of discharge from the ED (36). A third retrospective study of 62,495 admissions to hospital from the EDs of 3 tertiary urban hospitals in Perth, Australia from 2000-2003 showed that ED overcrowding (measured on the locally developed "Overcrowding Hazard Scale", >2 vs. ≤ 2) was positively associated to mortality in admitted patients within 2, 7, and 30 days. The 95% CI for RR was 1.1-1.6, 1.2-1.5, and 1.1-1.3 respectively (37). Three single center studies confirm the association between ED overcrowding and mortality within 10 days in admitted patients (38), 28 days for all patients (39), and 30 days in admitted patients (40), respectively. A study that included 3,973 admissions of trauma patients who triggered a trauma-activation revealed a significant increase in in-hospital mortality per minute increased EDLOS (95% CI for OR 1.006-1.010). The analysis was adjusted for trauma severity and age. Multivariate analysis indicated that EDLOS was associated with the anatomical distribution of injuries, rather than the derangement of physiological functions (possibly indicating time spent on other interventions rather than stabilization of vital parameters; e.g., reducing fractures) (41). In contrast, a report from three Italian trauma-centers revealed no positive association between EDLOS and mortality in trauma patients admitted to hospital (42). The view of trauma activations drawing resources from other groups of patients is supported by a US single-center study, which showed that patients presenting with potential acute coronary syndrome (ACS) during a trauma activation in the ED suffer greater risk for 30-day adverse cardiovascular events (43). Another single-center study that enrolled 171 patients failed to show any difference in waiting time for computed tomography (CT) of the head in patients with stroke-like symptoms presenting in conjunction to a trauma activation, compared to those who did not (44). A study addressing a total of 1,016 patients admitted to the internal medicine intensive care unit (ICU) from the ED of an academic hospital in Helsinki, Finland revealed no significant association between

the EDLOS and in-hospital mortality or health-related quality of life 6 months after the care episode (45). Another single center study addressing 43,484 patients admitted from the ED of an academic, tertiary referral hospital also did not establish an association between EDLOS and in-hospital death (46).

The effects of ED boarding on mortality have also been explicitly addressed in several studies. For example, a retrospective review of 50,322 ICU patients admitted from US EDs in 2000-2003 showed that patients experiencing ED boarding >6hrs suffered significantly greater mortality than patients boarding in the ED <6hrs (10.7% vs 8.4% mortality in the ICU, 17.4% vs 12.9% during the hospital episode) ($p<.01$ and $p<.001$, respectively). No differences in age, gender, and do-not-resuscitate status were revealed (47). These results are supported by the findings of a single-center study in a US level-I trauma center (48). Another single-center study of 41,256 undifferentiated inpatient admissions in a US academic ED showed that patients boarding in the ED ≥ 12 h experienced 4.5% in-hospital mortality while the corresponding number for patients boarding <2h was 2.5%. A positive association between ED boarding time and IPLOS was also reported (49). A study of ICU admissions from Australian EDs at 45 hospitals (48,803 cases) failed to establish any significant association between EDLOS and in-hospital mortality (95% CI for OR 0.99-1.02 per additional hour) (50). A main difference with this study compared to the other two is that the total EDLOS was measured as the exposure, while Chalfin (2007) and Clark (2007) measured the time after the decision to admit the patient to the ICU was made.

Although not explicitly addressed in all the studies accounted for above, it could be argued that the increase in inpatient mortality reported in several of the studies discussed is due to an admission-bias, where only the sickest patients are admitted to a hospital bed at times of access block. The possibility of such bias was addressed explicitly in an Australian study of three academic EDs, which failed to show any significant association between hospital occupancy and the probability of inpatient admission from the ED (37). The study conducted by Guttmann (2011) occupies a special position, as it reports an increased mortality among patients discharged from the ED (36), rather than in patients admitted to hospital. These results suggest that access block could be associated to risk taking behavior in ED providers.

Other studies have addressed process measures rather than medical outcomes or mortality. Among them, several studies report associations between ED overcrowding and the timeliness of time sensitive interventions (e.g., antibiotics administration, pain management, and management of patients with potential ACS). Timeliness of care is one of the six core dimensions in the working definition of quality of care proposed by the World Health Organization (WHO) (51).

Delays in antibiotic therapy have been described in three US single-center studies (52-54). An association between ED overcrowding and delays in pain management was described in a study of two US EDs (55), as well as in several single-center studies (56-59). A single-center study of 1,229 patients with long-bone fractures reveals that delays in pain-management are also present in the pediatric setting (60). In a retrospective review of 3,452 patients who received thrombolysis in 25 community and teaching EDs from 1998-2000, ED overcrowding was found to be associated with increased door-to-needle time (29). When studying more than 40,000 cases of non-ST elevation myocardial infarction (NSTEMI) in the CRUSADE registry (comprising 550 US hospitals), longer EDLOS was associated with impaired adherence to guidelines and increased risks of recurring acute myocardial infarction (AMI), but not with in-hospital death (61). A single-center study conducted at a US academic hospital ED reported an association between ED overcrowding and adverse cardiovascular outcomes in both ACS-related (18% of cases) and non-ACS related chest pain (62).

ED overcrowding has also been associated with various other process delays. For example, an association with delays in steroid administration in children with acute asthma was reported in a single-center study conducted in a US pediatric ED (63). A retrospective review of 558 patients who had bacteria growing in blood cultures taken in the ED of a single academic center in Taiwan revealed a positive association between ED overcrowding and blood-culture contamination odds ratio (OR) 1.01-2.59 (95% CI) (64).

Still other studies address preventable medical errors in the context of ED overcrowding. For example, a retrospective review of 533 patients from four Massachusetts EDs enrolled in the National ED Safety Study (NEDSS) revealed a positive association between ED overcrowding and preventable medical errors (PMEs) in AMI, asthma exacerbation, and dislocation requiring procedural sedation. The 95% CI for OR of PME was 1.03-5.81 in the fourth vs. first quartile of ED overcrowding (65). Another retrospective review of 1431 admissions from the EDs at two urban academic hospitals in Boston, US, revealed that ED boarding time was positively associated with home medication delays (95% CI for OR 1.05-1.10 for each additional hour boarded), but negatively associated with delays in cardiac enzymes (95% CI for OR 0.88-0.97) (66). The same author showed that patients boarding for more than 6 hours experienced more undesirable events (during their boarding time) than patients boarding for <6 hours (23.0% vs 42.1%) in a single-center study (67). Another single-center study, conducted in Canada, revealed that the odds of an in-hospital adverse event increased for each additional hour spent in the ED (95% CI for OR 1.004-1.050) (68). Considering that EDLOS may reflect access block (i.e. a crowded hospital), the two latter studies may have detected effects of hospital crowding, rather than ED overcrowding.

A frequently cited effect of ED overcrowding is that it causes more patients to leave the ED without being seen (LWBS). As mentioned before, LWBS has

recently been appointed one of seven outcome measures to be systematically reported by Swedish EDs (14). The fraction of ED patients who leave without being seen has been reported to be about 2% in the US (69), 3.3% in the UK National Health Service (NHS) (even though there is considerable variation between trusts) (70), and ranging from less than 1% to as much as 15% in other countries around the world (70). A Canadian study of 4.3 million patient visits to 163 EDs in Ontario in 2003-2004 revealed an overall proportion of LWBS of 3.1% (range 0.1-12% between facilities) (71). Data from the NHAMCS dataset indicate that LWBS rates are similar in children <18years as in adults, with 1.8% reported in one study (72). Currently, no national level data are available in Sweden.

The association between LWBS and long waiting times in the ED has been reported in several studies (73-77). Long waiting times was also the most common reason for leaving the ED among 498 LWBS patients who were contacted by telephone in a study conducted in Alberta, Canada (74). In a survey performed at a single-center urban academic ED in 2010, 340 patients (91% response rate) were questioned about how long they were willing to wait in the ED before leaving. Results showed that 51% were willing to wait for up to 2 hours, 17% for 2-8 hours, and 32% would wait indefinitely (78). Another finding that may or may not be mediated through increased waiting times is the association between the physician not being trained in emergency medicine (EM) and increased LWBS rates reported in a single-center study performed in a San Francisco ED (79). A US single-center study of an urban academic ED addressed the association of LWBS to ED overcrowding and found a positive association (80).

Nonwhites, Hispanic, Medicaid and self-pay patients have been reported to be more likely to LWBS, while patients presenting due to musculoskeletal complaints and poisoning/injury/adverse events were less likely, in an analysis of NHAMCS data from 1998-2006 (81). An Australian review of the literature reported that LWBS was associated to lower triage priority, younger age, and longer waiting times (82). An association to younger age was also reported in the study conducted in 163 Canadian EDs, cited earlier (71). The role of lower triage acuity is supported by NHAMCS data (72) and by a single-center study from the UK (83). An association between LWBS and low income was reported in an evaluation of 262 Californian EDs (84).

Interestingly, an association between LWBS and living in proximity of the hospital was reported in a Canadian single-center study (85). More than half of patients who LWBS were found to seek treatment in other locations within 7 days (74), 4 days (86), and 3 days (75) in three different studies. Even though many patients who LWBS seek care again, few LWBS cases revisit the ED and become admitted to hospital: <1% (86), 2.8% (74), 4% (76), and 5% (87) in four different study populations. One out of 498 patients who left the ED without being seen was subject to urgent surgery within 7 days, in one study (74).

During recent years, the condition of Leaving Without Being Seen (LWBS) has been delimited from what is called Leaving Against Medical Advice (LAMA). Most of the studies cited above do not account for whether LAMA patients are also included. LAMA numbers have been found to exceed LWBS numbers in a Swiss single-center study of 307,716 ED visits (88).

Apart from the patient centered outcome measures reported above, the financial effects of ED overcrowding have been addressed directly in some studies. For example, an evaluation of nearly a million admissions from the EDs across 187 hospitals in California revealed a 1% increase in the cost per admission on days with high ED overcrowding, which translated to costs of 17M USD in 2007 (34). Even though not explicitly mentioned, this result could also be explained by an admission-bias, where only sicker patients (who consume more resources) are admitted to the hospital at times of access block. Two US single-center studies reported that reducing ambulance diversion (89), as well as reducing boarding (90), increased hospital revenue. Increased EDLOS for chest pain patients has been shown to result in significant revenue loss to hospitals (91, 92).

Causes of ED overcrowding

The IOM highlighted the issue of availability of inpatient beds in ED overcrowding by stating that “Emergency departments (EDs) are frequently overloaded, with patients sometimes lining hallways and waiting hours and even days to be admitted to inpatient beds” (6). Several researchers and government officials agree on that the availability of inpatient beds is an important regulator of ED output (10, 12, 20, 27, 93-96). A study comprising data from 147 hospitals in the UK reports that the inpatient bed occupancy in the hospital is positively associated to the proportion of ED patients who do not meet the four-hour goal (97). The association between inpatient bed occupancy and EDLOS has been confirmed in several other studies (98, 99). Obstruction to ED output due to unavailability of inpatient beds is often called access block (100, 101), which could potentially induce the admission-bias discussed before. Apart from this important output regulator, other forms of mismatch between demand and supply are frequently cited as driving ED overcrowding, both in Europe and in the US. Some of these are elaborated below.

Early efforts to identify the causes of ED overcrowding suggested that inappropriate use of the ED was important (26, 28), for example by patients making non-urgent visits and by “frequent-flyer” patients. Other suggestions were seasonal illnesses and inadequate staffing (26). A strong trend to increasing use of the ED has been reported both in the US and elsewhere. The IOM reports that while the US population grew by 12% from 1993-2003, the number of ED visits grew by 26% (90.3-113.9M) (6). A more recent study of trends in NHAMCS data

shows that the number of annual ED visits grew by 1.9% per year from 2001 to 2008, which exceeds population growth by nearly 60%. In the same study, the mean ED occupancy in the US increased by 27% from 2001-2008 (or 87 million additional patient-hours in 2008 compared to 2001). An increased practice intensity (e.g., increased use of lab tests, etc.) was proposed as being the main driver of change (102). Even though not explicitly stated, practice intensity could reflect more frequent periods of access-block (during which ED staff invest more effort in ruling out time-sensitive conditions, in order to be able to discharge patients home). Another report describes a 32% increase from 1999 to 2009 (an increase from 102.8 million visits in 1999 to 136.1 million visits in 2009) (17). Increasing volumes of ED visits have been reported in many other countries, including Australia, Canada, Finland, France, Germany, Italy, Netherlands, and the UK (11). The case holds true for several EDs in Sweden as well (16).

Apart from the increasing demand for ED services by patients (20, 103-105), the supply of emergency care is decreasing in many places where EDs are discontinuing operations (22, 106). For example, the AHA annual surveys revealed that the number of hospital EDs in non-rural areas in the US decreased by 27% from 1990-2009 (107). Profound decreases have also taken place in Sweden during the last decades, according to the National Board of Health and Welfare (13). From 2011 to 2013, the number of hospital-affiliated EDs in Sweden decreased from 74 to 70 (13, 14).

The appropriateness of ED visits has frequently been discussed in the context of the increased demand for ED services (11). A growing number of uninsured individuals who lack proper access to the healthcare system are sometimes suggested to put additional strains on the US system (3, 6, 10). ED overcrowding has been reported worse at US hospitals serving large proportions of uninsured patients, in a paper published in 2003 by the US General Accounting Office (GAO) (10). After the 1986 enactment of the Emergency Medical Treatment and Labor Act (EMTALA) (108), US EDs must screen and stabilize all patients with medical emergencies regardless of their ability to pay. This is sometimes blamed for increasing inappropriate presentations by the uninsured. However, a more recent review of the literature suggests that the importance of presentations by the uninsured is overstated (12, 109, 110). Moreover, ED overcrowding is also prevalent in countries where access to the healthcare system is universal and publicly funded (11, 13, 16). Inappropriate ED use by patients presenting with minor problems has also been proposed as being an important cause of ED overcrowding (11), but this view has been challenged lately (12, 23, 102). For example, a study of 4.1 million patient visits to 110 EDs in Ontario, Canada reported an increase in EDLOS of only 4.2-6.0min (95% CI) for every additional 10 low-complexity patients arriving during an 8-hour period (111). Another proposed causal mechanism for the increase in ED presentations is that patients may prefer the ED to the primary care system due to perceived better access to

specialist physicians and diagnostic modalities in the ED (11, 12, 110). Apart from these trends on the macro level, several specific causes of ED overcrowding have been discussed in different reports. Anantharaman and Seth (2015) provide an overview of the most frequently cited, in the previously cited book chapter (12).

Input factors

- Patients lack easy access to primary care
- Patients prefer the ED to primary care in order to gain access to specialist physicians
- The ED is used by uninsured and non-urgent patients (this has been questioned)
- The population of patients in the community is of high-acuity

Throughput factors

- The clinical workload is high, due to a shortage of ED providers. As in any queuing system, the number of available providers can be a rate-determining step when there are many customers in the system
- ED processes are inefficient and cause patients to wait for the main part of their stay (i.e., most of the time spent in the ED is not spent participating in value-adding activities)
- There is a shortage of physical space in the ED. Such shortage may become a rate-determining step analogous to what was mentioned in conjunction to shortage of ED providers
- The patient characteristics in the ED population become more challenging (e.g., increasing age, complexity/acuity, often requiring extensive workup, admission, and prolonged periods of boarding in the ED)

Output factors

- Shortage of bed capacity in inpatient wards (in-hospital bed occupancy rates exceeding 85% are cited as the most common cause of ED overcrowding)
- Residents from inpatient clinics scrutinize the decisions made by attending ED physicians impose additional delays
- Care processes in the inpatient setting are slow (e.g., delays in ordering necessary diagnostic tests), which increases IPLOS and keeps hospital bed-occupancy high

- Capacity shortages in community services (e.g., nursing homes) cause inappropriate delays in inpatient wards, causing long IPLOS
- Seasonal variations in ED overcrowding (e.g., due to temporary closings of hospital wards which thereby affects ED output)

Different measures that have been taken in order to ameliorate ED overcrowding will be discussed in the next section.

ED overcrowding: interventions

The IOM embraces the systems perspective of ED overcrowding in its report (6), stating that “Hospital EDs and trauma centers have little control over external forces that contribute to crowding, such as increasing numbers of uninsured or the growing severity of patients’ conditions”.

Its view of boarding and access block was discussed in the previous section. The institute saw the potential to increase ED efficiency by applying the systems-wide approach and implement “innovations in industrial engineering”. More specifically, the institute exhorted hospital executives to “adopt enterprise-wide operations management and related strategies to improve the quality and efficiency of emergency care”.

Kolker (2013) elaborates on the detailed interdependencies of a healthcare system in a chapter of a recently published book on managing patient flow (112). This will be elaborated in the section “A systems perspective on ED overcrowding”. Some authors claim that reshaping reimbursement systems would help ameliorate ED overcrowding. IOM states that a main issue is that there are “no negative financial consequences for operating crowded EDs”, and that this maintains the problem (6). Schneider (2008) agreed when stating that the present US system is perfectly designed to produce ED overcrowding and that unscheduled hospital admissions should be better reimbursed (113). Apparently, admissions initiated in the ED are not always less reimbursed than planned admissions, according to another US single-center study (114). There is an ongoing discussion about tying reimbursements to patient satisfaction. In the US, Press Ganey surveys have been a proposed tool. This causes some concern, as the surveys are struggling with low response rates and thereby may yield biased results (115). In other countries (e.g., the UK), ED overcrowding has been addressed in the reimbursement systems by creating economic incentives for keeping waiting times in the ED short. A famous example is the so-called four-hour target in the UK. The target was introduced in 2004, as the English government tied economic reimbursements to the rule that 98% of patients should stay in the ED no longer than four hours (116). 98% was transformed to 95% in 2010. The target has been subject to criticism (117) and some researchers request its replacement by more granular performance indicators

(118). A recent review of the target suggested that it may have resulted in some benefits to patients, but that it does not reach those in greatest need. Moreover, it has imposed significant costs to the healthcare system and may expose staff to high levels of stress (116). The target is still in place in the UK and apparently there is not yet full consensus as to whether it is an intervention of net benefit. In Sweden, nationwide effect measures for ED performance have been developed recently (as described earlier), but their exact use and the effect of their implementation remains to be evaluated (14, 16). Several researchers have suggested that publicly reporting ED overcrowding measures may stimulate hospital administrators to take the issue more seriously (11). There are no national reimbursements tied to EDLOS in Sweden, but several county councils and regions have implemented versions of the four-hour target locally (16).

Apart from access block and reimbursement systems, another macro level mechanism affecting ED overcrowding is the accessibility to scheduled outpatient care (e.g., primary care). Good accessibility has been suggested as an important preventive factor (11, 110). This is supported by several countries with robust primary care systems that report low levels of overcrowding (11). However, overcrowding is still prevalent in these countries and insufficiencies in the primary care system are likely to be only part of the problem.

Several authors suggest that hospitals that have been the most successful in alleviating overcrowding are those that have recognized that the problem is system-wide and not confined to the ED (6, 93, 119). Full capacity protocols for distributing boarding ED patients throughout the hospitals are supported by many instances (2, 20, 120). When asked, patients appear to prefer boarding in inpatient hallways to boarding in the ED (121) and such practices appear not to be associated to increased mortality (122).

Apart from the macro level mechanisms discussed above, several specific interventions aimed at ameliorating ED overcrowding have been described. A frequently cited review article authored by Hoot (2008) listed commonly studied interventions. These included hiring additional staff, implementing observation units in the ED, improving hospital bed access, performing non-urgent referrals to primary care, ambulance diversion, ambulance destination control, implementing crowding measures to monitor and predict episodes of crowding, and using queuing theory to optimize flow (26). In the same year, the ACEP listed potential solutions to ED overcrowding (20). The ACEP list was unique in that it attempted to rank the impact and viability of different alternatives. The high-impact solutions were the solutions found most effective and were supported by the ACEP.

The following solutions were listed as high impact:

- To move ED patients who have been admitted to the hospital out of the emergency department to inpatient areas, such as hallways, conference rooms, and solaria
- To coordinate the discharge of hospital patients before noon. Research shows that timely discharge of patients can significantly improve the flow of patients through the emergency department by making more inpatient beds available to emergency patients
- To coordinate the scheduling of elective patients and surgical patients

The following additional solutions were listed as potentially effective:

- To implement bedside registration of patients in the ED
- To implement fast track units for certain patient groups in the ED. Fast-tracks for less acutely ill patients have been criticized for drawing resources from the sicker patients in the ED and have lost some popularity. Recent approaches using discrete-event simulation have aimed at developing more flexible strategies, where ED workload controls the allocation of resources to the fast track (123).
- To implement observation units in the ED
- To implement physician triage in the ED
- To cancel elective surgeries in order to free in-hospital bed capacity

The following solutions were listed as not effective:

- To expand the ED. The ACEP claims that with less pressure on the system, the hospital might simply expand into the additional space, increasing rather than decreasing the number of admitted ED patients who are boarded in the ED
- To use specified areas for discharged patients on inpatient floors. These tend not to be used by nurses except when the full capacity protocol places stress on their parts of the system
- To employ hospitalists to coordinate patient care. Using hospital-based physicians, such as hospitalists and intensivists, has been shown to decrease hospital lengths of stay but not emergency department waiting times
- To put ambulances on diversion status. This is fairly common in the US, and the ACEP argues that it has become increasingly evident that it does not have the intended effect in most circumstances. Some reports suggest that ambulance diversion creates delays and impairs

timeliness of pre-hospital care (124) and it has lost popularity during recent years. It is also prohibited in some US states (12). Prohibiting the practice in Massachusetts, US, was not associated with increased EDLOS or ambulance turnaround time (125)

After publishing the above suggestions, the ACEP has been criticized for not reporting the method used when arriving at the rankings (25).

Anantharaman and Seth (2015) also addressed the issue of non-effective solutions and misconceptions about ED overcrowding by listing the most important of them in the book-chapter cited previously (12):

- Primary care patients inappropriately presenting in the ED are the main cause of ED overcrowding. The concerns about this view were elaborated in a previous section
- An effective measure against ED overcrowding is to arrange with other health centers that can accept patients for transfer when the ED is overcrowded. The main reason for the inefficiency of this strategy is that it requires substantial logistics and the numbers of patients transferred are often inadequate
- It is effective to recruit more staff that can manage the patients boarding in the ED. This ignores the fact that ED overcrowding happens almost on a daily basis and that there is rarely a surplus of staff to recruit for this task
- The authors agree with the ACEP in that cancelling elective procedures is not effective. It causes patients to be unhappy, increases the queues for elective procedures, and is of economic detriment to the hospital
- Another misconception listed is that the level of care provided to inpatients is the same irrespective of which hospital ward they are located in. The authors argue that patients tend to be managed more promptly in their dedicated discipline's ward
- The last misconception listed is that the ED overcrowding problem is confined to the ED and that the ED is the only department that should solve it. This issue will be elaborated in the part "A systems perspective on ED overcrowding"

Anantharaman and Seth (2015) also discussed specific strategies used to ameliorate ED overcrowding, from the perspective of Asplin's conceptual model (12):

Interventions aimed at reducing input:

- To implement telephone advisory services in order to divert patients away from the ED. According to the authors, this has not proven any impact on ED overcrowding or access block
- To educate the public about the need to reduce ED visits. The evidence base for this practice is not entirely clear; however, a Finnish study showed that the implementation of a new triage system in conjunction to public education reduced ED visits (126)
- To triage patients out of the ED. The authors claim that such interventions have been unpopular since they both consume resources and tend not to be appreciated by patients. Moreover, it is hard to judge the inappropriateness of an ED visit with the limited information available in triage
- To expand home-based care and community outreach programs. There is evidence supporting that such measures cause reductions in ED visits and unscheduled admissions in patients with chronic conditions (127, 128)

Interventions aimed at improving throughput:

- To co-locate primary care facilities within EDs. Anantharaman and Seth (2015) argue that this practice has not been associated with any significant reductions in ED waiting times or access blocks. This would be supported by the discussion in the “Causes of ED overcrowding” section, indicating that primary care patients in the ED are a limited problem. In a recent Cochrane review, the evidence available was assessed as of low quality (129)
- To identify complex patients early (e.g., with many comorbidities, the elderly)
- To decrease alcohol-related ED presentations by screening and subsequently referring patients to alcohol management clinics
- To implement bedside registration in the ED
- Implementing management principles such as LEAN, queuing theory, and team triage. However, a recently published article reported that the implementation of LEAN in several EDs in Ontario, Canada, was not associated to any change in the 90th percentile of EDLOS (130)
- To implement ED observation units (EDOUs). EDOUs have been shown to lower costs and improve patient safety. Chest pain, appendicitis, asthma, kidney stones, skin infections, allergic reactions are examples of suitable conditions to care for in the EDU, and the

length of stay (LOS) should be less than 24 hours. EDOUs have been increasingly acknowledged by payers in the US during the last decades (131).

Interventions aimed at improving output:

- To create institutional awareness about ED overcrowding and adverse effects, and thereby acknowledge the system's perspective of the problem
- To grant ED physicians the right to admit patients, without subsequent review of hospitalists
- Decreasing in-hospital bed occupancy rates to reduce access block
- To create hospitalist teams that work closely with patient families to facilitate the discharge process and with screening for complications (that could cause the patient to be readmitted)
- To increase bed capacity in the healthcare system as a whole and to facilitate transfer of patients that need long-term care (e.g., the elderly) from acute care beds. In Sweden, this is somewhat obstructed by the organizational boundaries between county councils and municipalities, created through the Ädel-reform
- Creating additional beds in inpatient hallways. This is supported by the ACEPs view. Recent work by Viccellio (2013) indicates that patients prefer boarding in the hallways of inpatient wards to boarding in the ED (121) and that boarding in an inpatient hallway bed is not associated with increased mortality (122)
- To implement flexible surge management strategies. The feasibility of operating an ED on "disaster-mode" for prolonged times is not clear, but may increase institutional awareness about the situation

Anantaraman and Seth (2015) cite the output solutions as the most important. This agrees with the view held by the ACEP in their 2008 paper (20) and with what was discussed in the "Causes of ED overcrowding" section. The importance of ED output is supported by the framework of queuing theory, elaborated in the section "A systems perspective on ED overcrowding". Timing of discharges from inpatient wards will be further elaborated in the same section.

According to the view of a consensus conference sponsored by the journal Academic Emergency Medicine in 2011, the value of many of the traditionally proposed interventions is unclear, mostly because few rigorous evaluations have been conducted (106). In a systematic literature review aimed at describing interventions in the ED front-end organization, Wiler (2010) (94) described 16 interventions, only three of which were supported by class I evidence

(physician/practitioner at triage, tracking systems and “white boards”, kiosk self check-in). The other included interventions were: immediate bedding, bedside registration, advanced triage protocols and triage-based care protocols, dedicated “fast track” service lines, wireless communication devices, personal health record technology (“smart cards”), team approach patient care (“team triage”), resource-based triage system(s), waiting room design enhancements, full/surge capacity protocols, incentive based staff compensation, time to evaluation guarantee and referral to next-day care (“deferral of care”). Only five of the 54 reviewed articles were classified as of class I quality (randomized controlled trial, meta-analysis of randomized controlled trials or prospective study). The classification was made according to a modified version of the ACEP clinical policy review format (132). In a final remark, Wiler (2010) concluded that operational bottlenecks at the back-end of the ED (i.e., ED output) “ultimately lead to front end delays”.

The dominance of single center studies and prominent local variation in defining exposure (i.e. ED overcrowding) and outcome is an issue in ED overcrowding research and will be elaborated in the section “The international research agenda”. As a result, leaders should pay attention to local conditions when intervening with ED overcrowding.

Equality in ED overcrowding

It has been suggested that ED overcrowding is more pronounced in the largest metropolitan statistical areas, in areas with high population growth rates, and in areas with many uninsured individuals (10). Recent work suggested that hospitals with higher ED volumes are disproportionately affected by ED boarding (133). Some Swedish EDs appear to be more severely affected by ED overcrowding than others (16), but little work addresses equality in Swedish EDs in terms of patient characteristics. In the context of ED overcrowding, inequality in care has been one of the least studied dimensions of quality of care as defined by the IOM (134).

However, some studies address the subject. For example, a 2008 study comprising NHAMCS data on ED waiting times for 92,173 adults presenting to US EDs in 1997-2004, revealed that black and Hispanic patients experienced longer waiting times than white patients (95% CI 8.2-18.1%) and (95% CI 8.0-21.3%), respectively. The analysis was not adjusted for specific hospital site (18). The inequality was confirmed by another study of NHAMCS data on 138,569 adult ED visits from 2001 to 2005, which revealed that EDLOS was persistently longer for black patients (95% CI 8.1-13.1%), and Hispanic patients (95% CI 10.6-17.2%), than for white patients (135). In another study comprising 14,516 ICU and non-ICU admissions in 408 EDs in the NHAMCS dataset 2003-2005, it was reported that blacks were more likely to experience EDLOS >6h for ICU admissions than were whites (95% CI for OR 1.01-2.01) (136).

Quality assurance in the Emergency Department

The importance of medical errors as a cause of death and disability in the US was highlighted in the IOM landmark report “To Err Is Human: Building a Safer Health System” (137). According to a recent report profiling the healthcare systems in 15 countries, the problem is by no means unique for the US. For example, the proportion of sicker adults who experienced a medical- medication- or lab test error during the past two years (measured in 2011) ranged from 8-25% in the countries surveyed (138).

Although an entirely objective definition of quality is hard to make, there are several frameworks available. Anderson and Mottley (2015) provide a comprehensive review of the major ones (139).

During recent years, Michael Porter’s framework of value-based healthcare has gained interest in various healthcare settings. From the perspective of value-based healthcare, the main essence of quality is the patient health-outcomes achieved by consuming a monetary resource. Porter’s framework defines the outcomes for any medical condition in a hierarchy of three tiers (that contain two levels each):

- Health status achieved or retained
- Process of recovery
- Sustainability of health

The main challenges in applying the theory are to define the steps that add most value to the patient in order to allocate sufficient resources to realize them (and subsequently eliminating steps that do not add value) (140).

The IOM has defined quality in the context of six performance characteristics in the report “Crossing the Quality Chasm: A New health System for the 21st Century” (141). Anderson and Mottley (2015) discuss these from the context of emergency medicine (139).

- Safety – To avoid injuring patients while providing care intended to help them
- Effectiveness – To provide services based on scientific knowledge to those who could benefit and avoid providing services to those who will not benefit
- Patient centeredness – To provide care that is respectful and responsive to individual preferences, values and needs
- Timeliness – To reduce harmful delays and waits both for patients and caregivers
- Efficiency – To avoid waste of energy, equipment, supplies and ideas

- Equity – To provide care that is of constant quality, irrespective of personal characteristics such as gender, ethnicity and socioeconomic status

The six dimensions are essentially similar to those proposed by the World Health Organization (WHO) in their 2006 report “Quality of care: A process for making strategic choices in health systems” (51).

IOM raises concerns about that all six dimensions may be compromised during ED overcrowding, in the report: “Hospital-Based Emergency Care: At the Breaking Point” (6). The exact application of the above frameworks in the ED setting is outside the scope of this thesis, but the interested reader would be well advised to read the previously cited book chapter by Anderson and Mottley (2015).

A systems perspective on ED overcrowding

As was already discussed, many researchers and officials studying ED overcrowding agree on the role of inpatient beds and ED output. Several countries worldwide have reduced inpatient bed capacity over the last decades, among them Sweden, the United Kingdom, and New Zealand (142-144). Apart from the effects on ED operations, inpatient bed occupancy affects ED patients in several other ways. For example, high inpatient bed occupancy, or hospital crowding, frequently causes patients to be cared for in departments other than that which has the medical responsibility (145-148). Goulding (2012) reported five themes associated with jeopardizing patient safety in the context of outlier patients (149):

- Staff experienced inadequate time and/or resources to address the needs of their “own” patients as well as the outlier-patients
- Deficiencies in the communication with the department responsible for the outlier-patients
- Shortage of specialist-knowledge
- Suboptimal conditions in the ward
- Outlier-patients are frequently perceived as healthy; hence, they receive less attention than they should

An observational study of 58,158 admissions to an Australian academic hospital reported that as much as 19% of patients spend time as outliers and that being an outlier was associated with a 53% increase in the risk of experiencing an emergency call ($p < .001$). Outliers tended to be older, have a greater illness-severity, more complications and a higher mortality rate than others (150).

Another Australian single-center study of 19,923 patients reported a higher inpatient mortality rate in outlier patients than in others (RR 1.41, 95% CI 1.16-1.73) after adjusting for age, Charlson comorbidity index and ED boarding time (151).

A meta-analysis of 179 journal articles also reported that high inpatient bed occupancy is associated with increased rates of nosocomial infections (152). Research addressing specific pathogens has shown that this holds true for methicillin-resistant *Staphylococcus aureus* (MRSA) (153) and Extended Spectrum Beta Lactamase (ESBL) producing bacteria (154), as well *Clostridium difficile* (155). A study conducted on data from 182 German ICUs suggests that the intensity of care provided is more relevant than the sheer number of patients cared for, at least in the ICU setting (156). Two Finnish multi-center studies suggest that hospital crowding is associated with negative effects of health in staff when measured by initiation of antidepressant treatment (157) and sick leave (158).

Reducing the number of hospital beds has been linked to an increased rate of hospital readmissions in New Zealand (144) and the NHS (142). In an attempt to explain this phenomenon, some researchers have attributed high average in-hospital bed occupancy and frequent bed shortages with triggering a mechanism that causes the demand for accommodating new admissions to drive hospital discharges, thereby leaving patients at risk of premature discharge (159).

Several models have proposed an association between average bed occupancy and the frequency of acute bed shortages (160-162). The principles of queuing theory suggest that the likelihood of experiencing a delay (i.e. that no bed is available when needed by the next patient admitted) depends on the average utilization level of the system (i.e. the average bed occupancy) and that variation in the number of hospital admissions and inpatient length of stay (IPLOS) explains most of the short term variation in bed occupancy (93, 159, 163-166). Some argue that variability in admissions is more important than IPLOS (167). In a frequently cited article, Bagust (1999) reported that bed occupancy overflows increase as a function of inpatient bed occupancy (161). He argues that risks are discernible when the average occupancy exceeds 85% (four days of bed crisis per year), and that regular bed shortages are to be expected when average occupancy exceeds 90%. Moreover, Bagust (1999) claimed that negative effects of an episode of acute bed shortage are measurable during approximately two average inpatient lengths of stay after it happens. This means that a hospital with an average occupancy of 85% could expect to be disrupted for a total of eight weeks per year. Bagust (1999) also showed that bed crises could be quickly transmitted between hospitals in a system, when several of them operate close to maximum bed capacity simultaneously. Green (2013) discusses hospital occupancy from the framework of Erlang's queuing theory and elaborates the tradeoff between delays and average utilization level in an entire book chapter (93). Like Bagust (1999), she agrees that

full utilization and full availability are not compatible. This view was also supported by Bain (2010) (160).

In a review article, Allder (2010) described the diurnal, weekly, and seasonal variation of hospital bed occupancy. He reported that larger systems were less sensitive to variation than smaller systems due to their ability to pool resources and that systems that only handle scheduled appointments could achieve a higher average utilization level (167). Another measure proposed as a remedy to access block is synchronizing discharges from inpatient wards with the anticipated peak in inpatient bed requests made from the ED. Arguably, this is accomplished by performing discharges earlier in the day. Such practice may decrease conflicting demand for inpatient beds between patients not yet discharged and patients who await admission to the hospital (168-170). Peak ED occupancy has been found to lag approximately two hours behind peak ED inflow (102).

The effect of variation in system input is confirmed by a study of reform work in 200 hospitals in the NHS (164), as well as by Bagust (1999) in the previously cited article. Allder et al. (2010) reported that the daily mismatch of admission and discharge creates the most pronounced problems with bed shortages, although weekly variation also contributes significantly. Reduced discharge capacity (i.e., fewer physicians on duty) during national holidays and weekends is another important contributor, mainly due to unnecessary delays in discharges (159). One strategy that could be used to reduce variability in service time (i.e., IPLOS) is clustering patients into groups with similar needs (e.g. chest pain units). However, since this may reduce group size, there is a tradeoff between the advantages of the practice and the potential to pool resources in large systems (164). The employment of bed managers and proactive discharge planning have also been proposed as measures to prevent bed crises and allow a higher average utilization level (171). Additionally, some simulation studies show that scheduling elective surgeries could result in smoothed hospital bed occupancy (172-175). Interestingly, elective admissions have been shown to display as large variation as unscheduled admissions do, in some studies (176, 177). This variation would be an obvious target in any attempt to smoothen bed occupancy, as several studies highlight the role of variability in system input as a cause of acute bed shortages (165, 176, 178).

The reliance on fixed target occupancy levels in bed capacity planning is part of the hospital crowding problem (162). Alluding to the impact of variability in queuing systems, a system will be susceptible to delays as soon as either of the variables is subject to variation, if only average levels of input and throughput are considered in capacity planning (167). Queuing theory frameworks suggest that bed occupancy rates must sometimes be lower than desired, if the consequences of variability should remain within reasonable limits (93, 159, 161). Despite this, low occupancy rates are often interpreted as low operational efficiency, rather than a normal feature of a queuing system.

Even though some hospital systems may be undersized in terms of beds, it is probably too simplistic to only propose an increase in the number of hospital beds as a solution to the bed shortage problem. Allder (2010) requested better synchronization of admissions and discharges, reduced variation in bed occupancy over time, and mitigating capacity reduction during weekends and holiday periods (167). He also addressed the concept of bottlenecks in inpatient care and claimed that hospital systems must strive to minimize the use of inpatient beds as storage for patients who are “stuck in the daily flow” (i.e., spending time in beds simply waiting for procedures). This is especially important at the study site, where local economic incentives tying reimbursements to EDLOS (4-hour target) stimulates hospital admissions from the ED at times of better bed availability, thereby potentially maintaining and aggravating bed crises.

The increasingly important role of the ED as a source of inpatient admissions has been proposed by several sources (20, 103-105). For example, it was described in a 2012 report of analyses conducted on the Nationwide Inpatient Sample (NIS). Results showed that although the number of annual hospital admissions increased by 15% from 1993 to 2006, the number of admissions from the ED increased by 50.4%. Measured as the proportion of admissions, those initiated by the ED increased from 33.5% to 43.8% (110). The ACEP (2008) stated that: “The number of emergency visits has climbed dramatically, and most emergency visits and hospital admissions are unscheduled”. The Swedish National Board of Health and Welfare acknowledged the central position of the ED in the Swedish healthcare system in its 2011 report on waiting times (13).

In order to better understand ED operations from a systems perspective, different modeling approaches have been proposed (179). An important aspect is that a healthcare system typically consists of several smaller, but integrated, systems. Optimizing the performance of one part of the system does not necessarily improve the performance of the whole system (112). The hazards of optimizing individual processes have been expressed by the phrase “curing the process may kill the system” (180). Instead, quality initiatives in constituent parts should be aligned with each other in order to optimize the whole system. Additional advantages of modeling healthcare systems include the detection of critical relationships that may not be obvious to staff and leadership as a result of organizational silo-structures. Moreover, modeling endeavors frequently place people from different parts of an organization together, stimulating the exchange of ideas and perspectives.

According to Kolker (2013), the three basic components governing the balance of supply and demand in dynamic systems are (112):

- The number of patients entering the system, per time unit
- The number of patients leaving the system, per time unit

- The capacity of the system (which restricts the flow of patients through the system)

These components share many similarities with the conceptual model proposed by Asplin (2003). Kolker (2013) describes congestion, bottlenecks, and waste as potential consequences of a poorly balanced system. Systems must be understood to the level of their constituent subsystems and their dependencies in order for modeling to be successful. Typical subsystems in a hospital system include primary care, prehospital care, the ED, the ICU, the operating theater, and the inpatient wards. Apart from these subsystems and components, Kolker (2013) highlights the importance of knowing what proportion of patients experience each outcome and the frequency of transits between subsystems, in order for a model to be accurate.

After collecting the information above, queuing theory equations are useful tools for optimizing the tradeoff between the level of utilization in a system and the probability of experiencing a delay, but their detailed descriptions are outside the scope of this thesis. The interested reader would be well advised to read the previously cited chapter written by Green (2013) (93).

This section has mainly been occupied with discussing hospital crowding from the context of ED patients, but crowded hospitals exhibit effects on other patients as well. One direct effect is the cancellation of elective surgery (181-183). Cancellations cause longer waits, which in turn may cause detrimental patient outcomes. This has been explicitly studied in patients awaiting cholecystectomy (184) and coronary artery bypass surgery (CABG) (185).

Who should be admitted?

Hospital admission is often cited as the most expensive intervention an ED physician can make. However, the silo structure of many healthcare systems obscure this cost to ED physicians as well as to the primary care physicians who refer patients to the ED or admit them to the hospital directly. From the systems perspective, while hospital admission may reduce cost and effort in the referring/admitting department, additional cost and congestion may result in the recipient departments. In order to understand the incentives for admitting a patient to a hospital bed, it is important to understand which kinds of medical conditions frequently require hospitalization:

- Either the patient is medically unstable and requires the resources of inpatient care to become stable or have time-sensitive conditions resolved;
or

- The patient suffers from a complex condition that may not be very severe, but is too complex to be resolved in the outpatient setting.

Depending on the effects of initial diagnostic procedures and interventions, the above indications for hospital admission may be resolved in the ED. One example is patients who present at the ED with pyelonephritis and who may undoubtedly be too sick to be discharged directly after the diagnosis is made, but may feel much better after six hours of stabilization with intravenous fluids and antibiotics. Consequently, if provided in a timely fashion, initial interventions may render hospital admissions unnecessary in some ED patients. Another example is patients with non-specific abdominal pain (NSAP), which could indicate time-sensitive underlying conditions, but often does not. Appropriate radiological examinations and laboratory tests may allow for ruling out the time-sensitive conditions in the ED, and instead of admitting the patient to the hospital, outpatient follow-up could be arranged. To reevaluate a condition in light of the information provided by initial interventions and diagnostic procedures is a fundamental part of establishing prognosis and managing risk in emergency care.

When an ED patient is already admitted to the hospital, the reduced discharge capacity outside office hours causes most patients to spend at least one day in the inpatient ward. As a result, the patient's length of stay tends to be longer in the inpatient setting than what is necessary in order to stabilize the patient's condition or to perform the necessary diagnostic procedures. Potentially, this phenomenon creates an opportunity for savings by reallocating patients from the inpatient setting to the ED. Such reallocation inevitably contributes to the workload of ED staff. In some places, separate ED observation units (EDOUs) have been implemented to meet this demand. These units are generally situated in proximity of the ED, host patients for less than 24 hours, and have discharge capacity around the clock. If a condition is not resolved within the 24-hour timeframe, patients are admitted to an inpatient ward from the ED. The cost-effectiveness of EDOUs is increasingly recognized worldwide (131).

Tying economic reimbursements to EDLOS in order to facilitate ED throughput may impact the management strategy applied to patients presented in the ED. Some argue that such controlling mechanisms stimulate admissions from the ED to the hospital (186). For example, the four-hour target has been associated with a 35% increase in admissions from UK EDs (187). Many of these had IPLOS shorter than one day, suggesting that the increase in admissions is at least partly caused by patients who could be managed in the ED or in an ED. The cost-effectiveness of EDOUs is increasingly recognized worldwide (188).

The appropriateness of decisions about the level of care has also been discussed in conjunction to the elderly. Due to the complex nature of many of their conditions and their frequent comorbidities, elderly patients in the ED are often admitted to the hospital. For example, a study covering 4,680 visits made by nursing home residents to six Australian EDs showed that 57.5% of the patients were admitted,

but they only made up 2% of the total number of visits to the ED (189). According to Hughes (2012), people over 65 years of age consume 68% of acute inpatient bed days in the UK; this amounts to fifty-one thousand beds at any given time. He also reports that a reduction of inpatient admissions across all primary care trusts in the United Kingdom, to match the level of admissions from the 25% of trusts that admit the least, would allow the number of inpatient beds in the UK to be reduced by seven thousand (190). Results from a simulation study of the entire healthcare system in the city of Nottingham in the UK indicated that preventing only a small number of unscheduled hospital admissions in the elderly had profound effects on average in-hospital bed occupancy (166). As ED physicians often do not know the patient as well as the primary care physicians do, ED physicians may end up treating patients too aggressively, which is not always in line with the patients' own desires. Patients may also be subject to increased levels of stress in the ED setting compared to when managed in outpatient care. A strategy that has proven successful in avoiding unnecessary hospital admissions in nursing home residents is task shifting, where algorithms for providing care in nursing homes are developed. For example, a randomized controlled trial (RCT) of 680 patients residing in 22 nursing homes in Canada showed that implementing a clinical pathway for managing pneumonia reduced the number of hospital admissions by 12%, and also reduced IPLOS in admitted patients by nearly half (191). In another RCT, 150 patients with exacerbation of chronic obstructive pulmonary disease (COPD) were randomized 2:1 to nurse-administered home care and to inpatient admission. No significant differences in mortality at three months or in functional outcomes were reported (192). Nine of the 100 patients randomized to home care required inpatient admission within 14 days of randomization.

The failure to establish appropriate end-of-life care protocols may also cause nursing home staff to send deteriorating elderly patients to the ED in order to be evaluated by a physician, even though this may be contrary to the patient's wish. In Sweden, this is a problem outside office hours, when one nurse tends to be responsible for several nursing homes, whose residents he or she may not necessarily know very well.

Another frequently discussed issue of the boundary between hospital care and community care is the proportion of inpatient beds occupied by patients who wait for community initiatives, such as nursing homes or home services. In Sweden, as well as in the NHS, hospitals may charge the Social Service Departments for delays (142, 143). In a nationwide survey conducted in the UK in 2007, McCoy (2007) showed that few hospitals exploited this opportunity (193). Godden (2009) reported that delayed discharges only account for 1.6% of all inpatient bed days lost in the UK, and that Social Service Departments only contribute with 0.4% (142). Scott (2010) concluded that in Australia, improved access to residential care, rehabilitation services, and domiciliary support could heavily reduce the

demand for hospital beds (194). Even though few formal hypothesis tests have been conducted in Sweden, patients waiting for community care initiatives constitute a large part of the patients occupying Swedish inpatient beds (143). Since Swedish hospitals are not allowed to charge the municipalities for delayed discharges before five work days have passed, the municipalities are criticized of systematically allowing patients to wait in the hospital for this amount of time before accepting them in their facilities. This results in that treated elderly patients wait in inpatient beds, while sick ED patients board in the ED. In an attempt to describe other characteristics of patients subjected to delayed discharges (apart from old age), Costa et al. (2012) showed that morbid obesity, psychiatric diagnoses, and stroke were all associated with delayed discharge in a study addressing 17,111 unscheduled admissions to 10 hospitals in Ontario, Canada (195).

Apart from reducing unscheduled admissions, pressure on inpatient wards could be limited through a reduction in readmissions among patients who were previously hospitalized. A recent Cochrane review suggested that discharge planning is effective in reducing long-term readmissions (196). Another Cochrane review suggested that early discharge and more structured follow-up at home was not associated with negative outcomes in patients (197). A third Cochrane review focusing on patients with heart failure reported that implementing a clinical service organization decreased long-term readmission rates (127). Another study suggests that short-term follow-up can be used to prevent readmissions in heart failure (128). A meta-analysis of 29 RCTs showed that multidisciplinary strategies for managing chronic heart failure reduce hospitalizations and increase survival (198). Patient-level factors (199, 200), as well as inter-hospital variation (201, 202), have been suggested to influence readmission rates and could be targeted with interventions. A recent study conducted on 12,285 patients who were treated and released from 93 Canadian EDs with a diagnosis of heart failure showed that death or all-cause hospitalization within six months after ED discharge was less likely among patients who received follow-up by a familiar physician within the first month after ED discharge, compared to those followed-up by an unfamiliar physician; adjusted hazard ratio (HR) 0.86 (95% CI: 0.77–0.95). Any follow-up within 30 days of ED discharge was associated with a lower risk of a repeat ED visit or death at six months, HR 0.78 (95% CI: 0.73–0.82) for patients followed-up by a familiar physician, and HR 0.79 (95% CI: 0.72–0.86) for patients followed-up by an unfamiliar physician (203). A familiar physician was defined as a physician who had seen the patient at least twice in the year before the index visit (or during the index visit).

The possibility of an admission bias, where only the sickest patients are admitted to a hospital bed at times of access block, was discussed in the “Effects of ED overcrowding” section. Although most studies cited address inpatient mortality, Guttmann (2011) showed that mortality within 7 days of ED discharge was higher

among patients discharged at times of ED overcrowding (measured as waiting times in the ED), in a study of nearly 14 million ED visits in Canada. This suggests that access block may be associated to increased risk taking in ED staff (36). The admission-bias was addressed directly in a study of 62,495 unscheduled admissions from three Australian EDs. No significant association between the level of in-hospital bed occupancy and the risk of inpatient admission was reported in that study (95% CI for RR of admission per 10% increase in occupancy was 1.0–1.1). Results were adjusted for age, mode of transport, diagnosis, triage priority, source of referral, and the hospital attended (37). Some studies have addressed the issue of whether or not the decision to admit an ED patient is affected by system factors other than access block. For example, a study conducted on 14,969 patients presented to a Pennsylvania ED showed no association between the daily ED census and the pattern of inpatient admissions (204). Another study of 16 pediatric EDs showed that patients were more likely to be admitted if presented to an ED that employed resident physicians (205).

The issue of refused admissions due to bed shortage has been subject to considerable attention in the intensive care setting. For example, a study of refused admissions to six ICUs in the UK revealed that patients refused admission suffered a higher total 90-day mortality (46% vs. 37%) than patients admitted to the ICU. The analysis was adjusted for disease severity by stratifying for APACHE II in three groups (206). A more recent study addressing the same topic in 10 French ICUs showed an increased total 28-day mortality in patients who were admitted to an ICU after having been refused once due to scarcity of beds (207). No statistically significant mortality increase was observed in cases that were refused once and not subsequently admitted to the ICU. Disease severity was addressed as Glasgow coma scale (CGS) <8 , shock, creatinine $\geq 250\mu\text{mol/l}$ and prothrombin time ≥ 30 seconds. Shortage of beds was cited as a common reason for refusal of admissions to the ICU (46%) in an Australian study of 10 ICUs, but the study did not address patient outcomes explicitly (208). A systematic review published in 2004 included 10 observational studies and showed that in-hospital mortality was higher in patients refused ICU admission than in patients admitted to the ICU (OR 3.04, 95% CI 1.49–6.17). It was also reported that patients admitted during shortages of ICU beds were sicker, and that the ICU was less frequently used for monitoring during such circumstances (209). These findings would be suggestive of an admission bias in the ICU setting. A prospective evaluation of ICU admissions in a Chinese hospital revealed that the standardized mortality ratio was higher in patients who were refused ICU admission (1.24, 95% CI 1.05–1.46) than for those admitted, and that the increase was most marked in the middle range of the illness spectrum (210). A study addressing the attitudes of 43 critical care physicians reported that the attitudes towards refusal of ICU admission were subject to variation internationally (211). Even though the effect of refusing ICU admissions has been fairly well described, the lack of appropriate triage decision

rules for ICU admission has been highlighted, and recent attempts have aimed at developing a decision support algorithm (212).

The process of deciding whom to admit to the hospital from the ED is inevitably complex, demanding that the time sensitivity and complexity of a patient's condition be weighted against the benefits and costs of inpatient admission. Even though admission to the hospital may be the most expensive intervention available to an ED physician, the decision is often impacted by system factors as well as subjective factors. For example, a report from an ethnographic study investigating the behaviors of 260 emergency physicians and nurses in two EDs in Sydney, Australia during more than 1,600 hours stressed that reducing unnecessary hospital admissions was a primary goal in managing external relations (i.e., with other hospital departments) (213). Economic incentives aimed at keeping EDLOS short (i.e., the four-hour target) may stimulate hospital admission in patients that could be managed in the ED setting, especially at times of good bed availability. Admitting such patients to an inpatient ward not only drive resource expenditure, but potentially also maintains hospital bed crises.

The international research agenda

There is no apparent consensus about which quantitative measure of ED overcrowding is preferred. The 10 most common measures encountered in the literature were ranked in order of decreasing popularity by the Canadian Agency for Drugs and Technologies in Health (CADTH) and reported by Anantharaman and Seth (2015) (12, 214).

- Proportion of ED beds occupied by inpatients
- Total number of patients in the ED
- The proportion of acute-care beds occupied by patients (daily)
- EDLOS
- Proportion of time in which the ED operates at or above stated capacity
- Time from (inpatient) bed request to bed assignment
- Time from triage to assessment by an emergency physician
- Provider satisfaction
- The time taken from the instance when a patient achieves status as ready for a bed until the patient is transferred to an inpatient ward

- The number of staffed acute-care beds (active beds staffed and open in hospital)

Additionally, there are several ED overcrowding indexes. Examples are the Real-time Emergency Analysis of Demand Indicators (READI) (215), the Emergency Department Work Index (EDWIN) (216), the National Emergency Department Overcrowding Study (NEDOCS) scale (217), the Emergency Department Crowding Scale (EDCS) (218), and the ED work score (219).

Originally proposed by Reeder (2001) (215, 220), the READI index takes into account the bed ratio (the ratio between ED patients and ED treatment spaces), the acuity ratio (the sum of triage priorities/the number of ED patients; for triage systems where a high number indicates more severe disease), and the provider ratio (the ratio between ED arrivals and physician staff on duty).

The ED work score was developed at the Beth Israel Deaconess Medical Center in Boston, US, in 2006. The score predicts ambulance diversion by integrating the waiting room burden (measured as waiting room number/ED treatment areas), the throughput burden (measured as the sum of Emergency Severity Index, ESI, triage scores/the number of nurses on duty), and the boarding burden (measured as the number of boarding patients/number of ED treatment areas) (219).

EDWIN was proposed by Bernstein (2003); this index combines information about the number of patients in each triage category with the number of attending physicians on duty, the number of treatment bays, and the number of admitted patients in the ED. The ESI was the triage system used (216).

The EDCS takes into account the number of attending emergency physicians, the number of staffed ED beds, the number of critical care patients, the total number of ED patients, the number of staffed inpatient beds, and the hospital occupancy rate (218).

The NEDOCS scale was proposed in 2004 after analyzing data from the National Emergency Department Overcrowding Study. The measure was developed using data from 336 samplings from eight US academic EDs. The NEDOCS score depends on the following parameters: the number of ED beds, the number of hospital beds, the number of patients in the ED, the number of admitted patients in the ED, the number of respirators in the ED, and the longest admit time and waiting room time of the last patient put in an ED bed (217).

EDWIN, the NEDOCS score, and the ED work score predicted ambulance diversion well in a single-center study conducted at a US academic hospital. READI performed significantly worse (221). The READI measure also showed a poor correlation to staff perceptions regarding ED overcrowding in a single-center study of a US academic ED in 2003 (220). A comparison of READI, EDCS, EDWIN, and the NEDOCS score conducted at a single US academic center revealed significant correlation between the scales, but low correlation between

the proposed threshold of each scale and the perceptions among staff. The NEDOCS score had the largest area under the receiver operating characteristic (ROC) curve (222).

A comparison of EDWIN and the NEDOCS score in a single US academic center suggested good correlation between the two measures and a good discriminatory power in predicting ED overcrowding. The discriminatory power of NEDOCS was slightly better than that of EDWIN (223). The accuracy of NEDOCS for quantifying ED overcrowding in a high-volume setting was recently questioned in a study that failed to show any difference in EDLOS and LWBS rates between different levels of ED overcrowding, as quantified by the NEDOCS score. NEDOCS tended to overestimate the crowding situation compared to the subjective assessment made by the staff (224). The agreement between NEDOCS and the subjective assessment made by senior ED staff was low in an Australian single-center study as well (225).

In a comparison of EDWIN and the ED occupancy rate in predicting LWBS and ambulance diversion, which was conducted in six US academic EDs, the ED occupancy rate performed as good as or slightly better than EDWIN. Due to the relative ease with which the measure is calculated, the authors recommended its widespread use (226). This view was somewhat supported by Boyle (2012) (23) in a more recent publication. In the previously cited study comparing EDWIN, the NEDOCS score, READI, and the ED work score, none of the measures performed better than ED occupancy in predicting ambulance diversion (221). In a more recent publication, Crane (2014) argued that the existing measures describing ED overcrowding and workload fail to capture the complex nature of the phenomenon. He proposed a new measure called entropy, which takes the system complexity and flow of information into account more efficiently (227).

As is evident from the previous paragraphs, ED overcrowding measures are abundant and all try to capture the relation between supply and demand in the ED. The lack of common definitions was perceived as severe in a 2011 review article, and the author claimed the literature on ED overcrowding was of little help to practitioners and leadership (27). The problem with the relatively low quality of evidence is also highlighted by McHugh (2013) (25) and was mentioned in the “ED overcrowding: interventions” section of this thesis.

Apart from issues with study design, many studies investigating the association between ED overcrowding and bad patient outcomes fail to address the causal chain between them. For example, many of the studies that include process measures (e.g., time until antibiotics administration) lack mortality data, and vice versa. Possible explanations may be scarcity of comprehensive datasets and publication bias.

The scarcity of good datasets is well known and causes difficulty in addressing the full array of outcomes, as well as tracking patients between different parts of the

healthcare system. The lack of unique personal identifiers forces researchers to link datasets on other variables (age, sex, times of arrival and departure, and claims data), but this is not frequently mentioned in publications. Publication bias is not unlikely either, as many of the published researchers are either working in the ED themselves or work closely to those who do.

Even though EM is a fairly young medical specialty with evidence gaps to fill (228), it is reassuring that the research community is active in addressing organizational issues. Being the “window on healthcare” (6), EM systems arguably make good substrates for healthcare services research.

Overview of the Swedish healthcare system

The Swedish healthcare system was designed as one of the backbones of the Swedish welfare state. It dates back to the 1930s and has inspired other modern healthcare systems. According to Cerdá (2013), it made significant contributions to the ideas conveyed in the Beveridge report of 1942 (that laid the foundation to the welfare state in the United Kingdom) (229).

Broadly, the Swedish government assumes responsibility for controlling the healthcare system and for legislation, while the 21 county councils and regions are responsible for providing primary and secondary care. The municipalities are responsible for nursing homes and caring for the elderly and the disabled. Each of the county councils and regions has its own political leadership and is free to make healthcare prioritizations according to its own fashion. Each county council is responsible for managing its own healthcare resources, which are financed by income taxes imposed on the citizens, often with an additional small copayment for each patient visit. Additionally, there are two types of private healthcare options in the Swedish system:

- Healthcare provided by a private company that has a contract with the county council or local authority. In this case, costs for public and private healthcare are the same
- Healthcare provided by a private company that has no contract with the county council or local authority. In this case, costs are covered in full by the patient

All healthcare providers must register with the Health and Social Care Inspectorate (IVO), which is responsible for controlling Swedish healthcare providers. Employers are responsible for ensuring that staff has the competence required to maintain patient safety (230).

The county councils have considerable autonomy regarding which reimbursement system to use. The most common system for hospital care is called “Reimbursement per product group” (SE: “Ersättning per produktgrupp”). This system is variable, prospective, and makes use of bundled product groups (often defined by Diagnosis Related Groups, DRG). Product groups are bundled in order to minimize the difference in margins between different interventions and to prevent so-called “cream skimming”. The method has sometimes been criticized for incentivizing increased production and decreased costs (that could erode the quality of care over time). Pay for performance models have been tested on a limited scale. Capitation has traditionally been the most common reimbursement system in Swedish primary care, often weighted by Adjusted Care Groups (ACG) and the Care Need Index (CNI) (231). By implementation of the Vårdval reform in 2009, the Swedish government aimed at strengthening the patient’s position and stimulating competition in the primary care market. One of the most important reasons for implementing the reform was to improve accessibility to primary care (232).

As a result of the reform, the patient is free to choose primary care provider, and reimbursements are tied to the patient’s choice. Moreover, private companies are allowed to establish primary care facilities in competition with the publicly funded facilities. Private companies receive reimbursements based on the patients’ choice, in analogy with the publicly funded facilities (233). The reform has been subject to discussion since its implementation. For example, a report conducted by the Swedish Competition Authority in 2010 highlighted that the patterns of patient listings at primary care facilities had a large impact on the pattern of establishment of new primary care facilities. This yields more new establishments (and improved access to primary care) in areas where it is easy to achieve a large enough number of listed patients (234). It has also been suggested that the fixed reimbursement per patient stimulates new establishments in areas where people are healthy and consume little primary care, while facilities in other areas may need to discontinue operations. The Swedish National Audit Office recently claimed that the reform resulted in power being transferred from politicians and public officials to the citizens, but that the reform has had a strong controlling effect in primary care and has obstructed the maintenance of the ethical principles governing the Swedish healthcare system. In particular, the patients with the largest demand for care appear to be at a disadvantage. Moreover, the costs for primary care appear to increase, the effects on innovation and development are not stimulated in the way intended, and the positive effects in terms of improved accessibility appear to be more pronounced in healthier patients of higher socioeconomic standard (232). Another measure taken by the Swedish government in order to improve accessibility to healthcare was the care guarantee (“vårdgarantin”), which puts in legislation that patients should be guaranteed access to the healthcare system on the same day as they perceive the need to do so. A physical consultation is not

mandatory; it could be covered by a telephone consultation with a nurse at the national medical information portal, 1177.se. If a primary care provider makes the assessment that a patient needs to be seen by a primary care physician, the care guarantee states that this should be offered within seven days. If a patient is referred to specialist care, the patient should be offered a visit within 90 days. If a decision about treatment is made, the treatment guarantee states that the patient should receive the treatment within 90 days. The care guarantee is tied to governmental monetary reimbursements through the stimulation package “kömiljarden” (15).

The patients’ position was further reinforced in the new Patient Act, effective as of January 1, 2015. The act highlights the patients’ right to information (and an understanding of the information given) about the care process and about available alternatives, as well as satisfying the need for security, continuity, and safety. The patients’ freedom to choose a caregiver also extends from primary care and covers other outpatient options (235).

The Swedish Emergency care system

Apart from hospital-affiliated EDs, emergency care is available through the emergency services by telephoning 112; patients may dial this number at any time. The density and staffing of prehospital vehicles may be subject to local variation, due to the autonomy of the county councils in prioritizing healthcare resources. Since the mid-2000s, the national healthcare information portal has been available to patients by telephone and the Internet. There is ongoing work aimed at providing patients with more insight in their health care processes online, through the portal “Mina Vårdkontakter” (236).

In 2011, 74 Swedish hospitals provided emergency care to the about 9 million inhabitants. The number of hospital-affiliated EDs decreased to 70 in 2013 (13, 14, 237). The National Board of Health and Welfare approximates that about 2.5 million ED visits were made in Sweden in 2010. However, good approximations are hard to make due to the structure of the Swedish National Patient Register, which does not allow separate identification of ED visits that result in inpatient admission (these are coded as any other inpatient care episode). Therefore, reviews must largely rely on self-reported data from the EDs (13). ED overcrowding has been prevalent in Swedish EDs for several years and is apparently still increasing in many places (16). A review of 56 Swedish EDs by the National Board of Health and Welfare in 2006 revealed deficiencies in documentation, prioritization, waits, surveillance information, and communication to patients and relatives, as well as risk assessment and proper reporting of adverse events (238). Another review in the southernmost part of Sweden (239) in 2004 criticized the low status of working in the ED, as perceived by staff in inpatient specialist clinics.

Several Swedish hospitals started to develop triage-algorithms of their own in the mid-1990s. In the early 2000s, the Manchester Triage System was imported from the United Kingdom to a few Swedish hospitals, mostly in the western region. This initiated the local development of more advanced Swedish triage systems, of which Medical Emergency Triage and Treatment System (METTS) and Adaptive Process Triage (ADAPT) are the most well-recognized (237). METTS was developed further and renamed 'Rapid emergency triage and treatment system' (RETTS[®]) in 2013 (240-242); this is now the dominating triage system in Sweden. The use of fast-tracks in the ED has increased in popularity during the past few years (14).

In the 1960s, there were around 120 thousand inpatient beds in Swedish hospitals. As the responsibility for care of the elderly and disabled was transferred from the county councils to the municipalities through the Ädel reform in 1992 (243), the number of inpatient beds decreased to about 50 thousand (244). In a comparison between 16 countries in the OECD made in 2007 (Belgium, Denmark, Finland, France, Greece, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Switzerland, the United Kingdom, Germany, and Austria), Sweden had the lowest number of inpatient beds, with 2.6 beds per 1,000 inhabitants. The total number of beds was 25,653 in 2009, representing a reduction of more than 20% from 1999 (244).

Aims

The overarching aim of this thesis was to evaluate whether high access block, or hospital crowding, affected prioritizations of the appropriate level of care in patients presenting to the ED of a 420-bed emergency hospital in southern Sweden.

The specific aims of each constituent part are described in more detail below:

Part I: to evaluate whether the probability of hospital admission in ED patients was affected by access block (measured as hospital bed occupancy).

Part II: to evaluate the appropriateness of ED discharges made at times of access block, as measured by the 72h revisit rate.

Part III: to evaluate whether the probability of hospital admission in patients with acute abdominal pain was affected by the availability of inpatient beds in the hospital. A secondary aim was to evaluate the appropriateness of ED discharges at times of access block, as measured by the 72h revisit rate.

Part IV: to evaluate whether the probability of inpatient admission in patients with chest pain was affected by the availability of inpatient beds in the hospital. A

secondary aim was to evaluate the appropriateness of ED discharges at times of access block, as measured by the 72h revisit rate.

Part V: to evaluate whether the permeability of the ED front end decreased at times of access block (i.e. whether more patients were triaged out of the ED without being assessed by an ED physician). A secondary aim was to evaluate the appropriateness of discharges from this sorting facility, as measured by the 72h revisit rate.

Method

Description of the study site

Region Skåne is a geographical region in the southernmost part of Sweden, with a population of 1,25 million people (about 13% of the Swedish population). It is fairly densely populated, covering about 3% of the total area of Sweden. Hospitals in Region Skåne have struggled with budget deficits during recent years. Among them, the hospital at the study site, Helsingborg General Hospital had the greatest deficit (7.6% of revenues), according to a 2009 McKinsey report (245).

A comprehensive review of the patterns in unscheduled outpatient care in the region from 2008-2012 (246) revealed an increase of 5.5% in total unscheduled physician visits to primary care, but an 11% reduction during weekends. The report also revealed an 8% increase in the number of physician visits to unscheduled outpatient clinics other than primary care. Some of the latter concerned unscheduled outpatient visits to specialty departments, as visits to the hospital-affiliated EDs could not be isolated completely. The increase was greater during weekends (13.6%) than during weekdays (6.2%).

In June 2012, Region Skåne, two Danish regions and the Commonwealth of Massachusetts (US) signed an agreement to develop and reinforce collaborations within the Life Sciences discipline (247). One consequence of this was the initiation of a collaboration between Region Skåne and Harvard Medical Faculty Physicians (HMFP), which aimed at developing a high-impact organization for emergency care delivery in Region Skåne. The US partner in the project is currently the Department of Emergency Medicine at Brigham and Women's Hospital in Boston, Massachusetts.

The organization for emergency care delivery in the region was experiencing significant progress during the mid 2000's and was, for example, hosting an EM residency training program that attracted providers from several other countries. The program has subsequently suffered setbacks, largely precipitated by declining satisfaction among staff. The turnover rate has been significant since the turn of the decade, both among EM residents and EM nurses.

Shortly after the collaboration was initiated, consultants from HMFP conducted a site assessment at Helsingborg General Hospital, in the form of a pilot study. The most important recommendations described in the subsequent report were (248):

- To replace the current triage-to-specialty model with a triage-to-acuity model and employ specialized EM physicians in the ED
- To implement observation medicine
- To develop a clear strategic plan
- To develop metrics allowing for monitoring progress and data-driven management
- To train and retain skilled emergency physicians
- To develop a residency training program of high quality

Since then, the work has attained a region-wide perspective and the regional director has decided to expand the EM residency training program in the region (249).

Helsingborg General Hospital is currently one of four hospitals providing emergency care in Region Skåne. Its ED serves a population of around 250,000, which expands to more than 300,000 in the summer due to tourism. It is a teaching hospital, hosting education for medical students as well as emergency medicine residents. The annual ED census has increased from just below 60,000 to 65,000 from 2011 to 2013 (physician visits). Approximately 15% of patients arrive by ambulance. The emergency department is separated into units by specialty (internal medicine, surgery, orthopedics, otolaryngology). A complementary unit staffed by emergency physicians capable of handling various complaints except for psychiatric, otolaryngologic, ophthalmologic and pediatric complaints was introduced in 2010 and operates from 8am to 11pm daily. This unit assumed responsibility for all surgical ED patients beginning in spring 2013. There are separate EDs for children (<18 years of age) with medical conditions and for patients with obstetric/gynecologic, psychiatric and ophthalmologic complaints. Patients with suspected hip fractures or ST-elevation myocardial infarction (STEMI) diagnosed in the ambulance bypass the ED. Hand surgery, neurosurgery and thoracic surgery are not available at the hospital. The availability of endovascular surgery and percutaneous coronary intervention (PCI) is limited after hours (17:00-08:00). Patients with such needs are referred to Skåne University Hospital (SUS). At times of pronounced bed shortage, some patients are admitted from the ED to two other hospitals in the region, Ängelholm Hospital and Landskrona Hospital.

Upon arrival in the ED, patients are registered in the information system Patientliggaren®. Until January 1, 2012, a nurse performed the registration in what was called the “spot-check” facility. This nurse did not measure vital parameters or conduct any physical examination, but only recorded the main complaint and a short anamnesis. The spot-check nurse could admit patients directly to the ED, or (if their complaint was considered benign) refer them to

primary care without further assessment in the ED. If it was unclear whether the appropriate level of care was primary care or the ED, the nurse could refer patients to primary triage, which is an institution situated in the same physical facilities as the ED. Primary triage was staffed by a nurse who was able to conduct physical examinations and order laboratory tests. After evaluating patients, the nurse in primary triage could admit them to the ED, refer them to primary care or discharge them home. The decision-support “Triagehandboken” (250) was available in print and electronically to aid the primary nurse in making a decision. The majority of nurses in primary triage had undergone special training in how to use the “Triagehandboken.” Nurses in primary triage could consult one of the ED physicians when in doubt, but no physician was on duty in primary triage. Even though the name of the facility may suggest otherwise to an international audience, the main purpose of primary triage is not to stratify patients according to disease severity before admitting them to the ED. Rather, its main purpose is to sort out patients of low acuity and refer them elsewhere (e.g. to primary care).

Beginning January 1, 2012, the task of registration was delegated to a secretary and the spot-check facility ceased to be. The secretary could not refer patients to primary care, but was limited to admitting patients directly to the ED or referring them to primary triage. Strict guidelines were developed for the secretary to follow. Primary triage nurses could be asked to assist staff inside the ED during the entire study period. Primary triage could also be bypassed at times of long queues to the facility. Patients who were referred to the ED by a physician were directly admitted to the ED after registration, and hence bypassed primary triage. Patients arriving by ambulance were admitted to the ED directly. Patients who were referred to primary care from spot-check or from primary triage were guaranteed a medical evaluation by a nurse in primary care the same day or the day after (depending on hours of primary care availability, generally until 5pm). One primary care facility would accept patients outside office hours (until 8pm), but was located 15 minutes away from the ED by car. Patients often resented primary triage nurses’ advice to contact this facility.

After being admitted to the ED, patients undergo secondary triage (an algorithm for prioritizing patients depending on vital parameters and main complaints, similar to what is used in most EDs worldwide). The five-level triage system RETTS[©] (242) is currently used for secondary triage. The system was previously called ‘Medical emergency triage and treatment system’ (METTS) (240, 241) during the validation period, and the final RETTS[©] version was implemented in early 2013. One of the five levels indicates that there is no indication for emergency care and is frequently assigned to patients who are referred to another level of care by primary triage. RETTS[©] assessment is based on two kinds of factors, which together yield one out of five priority levels. The highest level from which the patient scores is always chosen. The two kinds of factors are:

- Vital parameters
- Main complaints (most have an associated ESS – “Emergency Symptoms and Signs” – algorithm. These algorithms were developed in collaboration with the users)

Table 1.
Vital parameters in the RETTS© triage algorithm

Triage category	1 (red)	2 (orange)	3 (yellow)	4 (green)	5 (blue)
Clinical parameter	Airway obstruction				Patient that does not need triage
	Stridor				
Oxygen saturation	SpO2 <90% with oxygen supply	SpO2 <90% without oxygen supply	SpO2 90-95% without oxygen supply	SpO2 >95% without oxygen supply	
Respiratory rate	>30 or <8	>25		8-25	
Pulse (beats/min)	Regular >130 or irregular >150	>120 or <40	>110 or <50	50-110	
Systolic bp (mmHg)	<90				
Consciousness	Unconscious, Seizures	RLS 2-3/somnolence	Disoriented	Alert	
Temperature [°C]		>41, <35	>38.5	35 – 38.5	

From secondary triage, patients are directed to separate units for surgery, orthopedics, internal medicine, otolaryngology, gynecology, pediatrics, ophthalmology, psychiatry and emergency medicine in a triage-to-specialty model.

Definition of study variables

Exposure:

Unavailability of inpatient beds, or access block, was measured as strata of in-hospital bed occupancy at the time of patient presentation in the ED. Other definitions of access block are encountered in the literature (e.g. average boarding time in the ED in excess of 8 hours), but were considered less appropriate due to the economic incentives to reduce EDLOS at the study-site. Occupancy was measured hospital-wide rather than for specific departments as full-capacity protocols frequently take effect when the hospital approaches full. Patients are then distributed between hospital wards that sort under departments other than that formally responsible for the patient. Therefore, measuring access block in separate departments may be misleading. Occupancy at the hour of patient presentation in the ED was preferred to measuring at a fixed time each day (e.g., at 06:00 in the morning), since the latter would not necessarily reflect the current situation very well. Traditionally, <85% in-hospital bed occupancy has been proposed as the

level to maintain in order to avoid excessive bed crises (161). However, since the mean hospital occupancy at the study site during the study period was 94.9%, <85% is not likely to reflect a situation of access block. Therefore, a hospital occupancy rate of <95% was used as a common-sense reference. Different levels of access block were illustrated through constructing occupancy-strata consisting of 5% increments. The exposure variable was tested for linearity in the logit across Parts I-V. Since it violated this assumption in part I-II and V, it was modeled as a continuous variable only in parts III-IV.

Outcomes:

Part I: Making inpatient admission the outcome measure for part I was straightforward. Inpatient admission is registered in Patientliggaren® when the patient leaves the ED and was readily available from this data source.

Part II: The appropriateness of ED discharges among patients treated and released from the ED at times of access block was evaluated through unplanned revisits to the ED within 72 hours of discharge. Even though this measure does not capture all detrimental outcomes patients may be subject to, it made an appealing choice, since it was appointed one of seven quality indicators for Swedish emergency care in 2013 (14). The appointment was preceded by thorough discussions among professionals in the field, e.g. within the context of the Akut Förbättring project. Physical ED records for patients who are advised to revisit the ED are stored at each specialty unit. Nurses indicate whether a visit is a planned revisit in Patientliggaren® upon patient arrival. This information was used to exclude planned revisits. Revisits resulting in inpatient admission were identified by linking data between subsequent visits registered in Patientliggaren®.

Parts III-IV: Parts III-IV were conducted in response to the finding of a significant interaction term between in-hospital bed occupancy and the ten most common main complaints in the ED in Part I. This finding indicated that the magnitude of the effect observed in Part I was different for patients presenting with different main complaints. Study outcomes in Parts III-IV were the same as in Parts I-II, in order to retain transparency. However, Parts III-IV also identified revisits made to the ED of a nearby hospital that frequently refers patients to the ED at the study site.

Part V: Part V differed from the other four parts in that it addressed prioritizations about the level of care made at the front-end (i.e., ED input) rather than at the back-end of the ED (i.e., ED output). Since a record of all ED units caring for a patient during the ED visit is kept in Patientliggaren®, information about the permeability of primary triage was readily available. The rationale for addressing the appropriateness of discharges from primary triage through unplanned 72h revisits was similar to what was reported in conjunction with Part II.

Covariates:

Age was readily available from the unique personal identifier, which is registered in the data sources (see data sources section below), along with other individual level data. Slightly different cutoffs were used in Parts III-IV compared to in Parts I-II, in an attempt to separate out patients with higher age (>80 years). In Part V, cutoffs were harmonized to the values specified in the algorithm followed by the secretaries when deciding who was to be referred to primary triage and who should be admitted to the ED directly.

Triage priority was identified as the first registered triage priority in Patientliggaren®. Even though patients can be prioritized towards a higher or lower acuity, the first value probably best reflects how soon a patient undergoes a first assessment by an ED physician.

When defining patients in terms of which ED specialty unit they belonged to, the last responsible unit registered was used. The reason for this is that often little is known about the patient's condition in the beginning of the care process (251), and patients are therefore sometimes subject to transfer between ED specialty units. The assumption is then that the specialty unit responsible for the final disposition assumes overall responsibility for prioritizing the level of care.

Referral status was retrieved from the regional billing system "patientadministrativt system i Skåne" (PASiS). All referrals made by a physician were treated similarly, irrespective of whether they were made by a physician in private or public practice.

The variables indicating presentation on a shift with high volume input to the ED or primary triage were constructed as dichotomous variables indicating presentation on one of the 25% of shifts subject to most visits (adjusted for shift type and unit).

Data sources

Patientliggaren®:

For the purpose of the research database, the main data substrate was individual level data on ED visits, retrieved from the information system Patientliggaren®. This system is used as an ED dashboard. There are three tables in the database. The table "Contact" is flat and contains the unique personal identity number ("personnummer") of the patient making an ED visit, along with time of initial registration, time of discharge, destination of discharge (inpatient admission, discharge to home, to primary care) and the admitting and discharging ED units, respectively. These variables are mandatory for all patient visits to the ED and are

perceived as being of high quality by the staff responsible for Patientliggaren®. The table “Event” is stacked and contains information about what happens to the patient during the ED visit. Specific events registered are: responsible nurse, responsible physician, physical location in the ED, main complaint, triage priority and responsible unit within the ED. Compliance in entering these variables is anticipated to be good, since staff generally perceives it as important to know where a patient is and who is responsible for the management of a particular case. Triage priority is probably reliable, since the mandatory efforts involved in monitoring patients in the ED are strongly tied to triage priority. The main complaint is registered in conjunction with secondary triage (which the vast majority of patients are subject to). There is also a field called “Process” (i.e., being part of the stroke process, the hip-fracture process, patients triggering medical or surgical alarms in the ED, patients serving in educational commitments, patients making planned revisits to the ED). Compliance in entering these “Process” measures is perceived as good. Another field is called “Aktivitet,” which includes activities like “waiting for physician” and “waiting for an inpatient bed.” The quality of these measures is questionable. The third table called “Revisit” (free translation), is flat and encompasses data on revisits. The number of revisits within 30 days is available, as well as the time until the next visit to the ED. The unique personal identifier and the time of presentation in the ED identify the rows in this table.

PASiS:

The billing system PASiS was used to retrieve data on referral status for ED patients. Even though there exists a non-validated field in PASiS indicating whether a visit is unscheduled or not (AKUT=JA/NEJ), PASiS could not be used as the single datasource, since it does not contain data on triage priority or time of discharge from the ED. In-hospital bed occupancy was retrieved from an application scripted by Lars Gustafsson in the informatics unit of Helsingborg General Hospital. The application was scripted in the QlikView® programming language and automatically reads the hourly occupancy on each inpatient ward from PASiS. Since a patient cannot be registered as residing in a ward before the discharge registration from another ward (region-wide) has been completed, these data are considered reliable. The data collected by the application are continuously used for bed management in all of Region Skåne.

Statistical methods

Normality in variables was assessed visually, along with the values of skewness/kurtosis and the Kolmogorov-Smirnov test. Fisher’s exact test was the preferred test for comparing proportions in all studies. In cases where this test was

too computationally intensive, the Chi2 test was used. Continuous variables were compared only in Parts III and IV (EDLOS). In Part III, the Mann-Whitney U test was used to make the comparison of EDLOS across the two strata of in-hospital bed occupancy. In the case of Part IV, the Kruskal-Wallis test was used for comparing EDLOS across four strata of in-hospital bed occupancy. Even though EDLOS was non-normally distributed in both Parts III and IV, the student's t-test and the ANOVA test were applied, respectively, for validation of the results from the non-parametric analysis. This was due to a recent controversy about the appropriateness of applying conventional non-parametric tests when sample sizes are large (252).

Logistic regression:

In order to isolate the effects of the exposure on the outcome from other variables influencing the outcome, multivariate models were constructed. Logistic regression was the method of choice. The method is popular for multivariate analysis in the health sciences, particularly because of its suitability for analyzing binary outcomes data (253-256). It is especially useful when the responses on the dependent variable are expected to be non-linear with one or many of the independent variables (predictors). The method is endorsed for its flexibility, which mainly results from making few assumptions about the distributions of the predictors (i.e., being normally distributed, linearly related or of equal variance within groups). Apart from being much more flexible than linear regression, another difference between the two is that the linear portion of the regression equation is not the endpoint, but is used to find the odds of belonging to a specific category of the outcome (253). A detailed review of the method is available in several standard textbooks (253-256).

Roughly, the purpose of any regression-modeling endeavor falls in either of three categories (257):

- Prediction. A predictive model is constructed in order to predict the outcome in a naïve case, i.e., a case that was not used when developing the model
- Evaluation. A model is constructed in order to evaluate the importance of a particular primary predictor of interest on the outcome
- Identification. This approach is more exploratory involving identifying important independent predictors of an outcome, e.g., aiming at identifying risk factors in large datasets

The present work is best described as a case of evaluating a predictor of primary interest. This is important, as the construction and interpretation of a regression model are influenced by the purpose of the analysis.

Interpreting effect size:

The overall effect size of the predictors in a logistic regression model (i.e., what proportion of the variation in the outcome is explained by the predictors in the model) was interpreted by the likelihood-ratio test and by Nagelkerke's R^2 . The likelihood-ratio statistic are computed as the difference between the likelihood functions of two compared models (e.g., a model including only a constant, and a full model), and can be referred to using the chi2 distribution (with degrees of freedom equal to the number of additional predictors in the larger model) for significance testing. If the test indicates a significant difference, the more complete model contributes new independent information as compared to the less complete model (253-255). It follows that the likelihood-ratio test can be used to evaluate the contribution of individual predictors. Additionally, several pseudo R^2 measures are also available for interpreting the overall explanatory power of the predictors on the outcome. Examples include McFadden's p^2 , Cox&Snell's R^2 and Nagelkerke's R^2 . The Cox&Snell measure was invented as a response to the criticism of McFadden's p^2 , whose values consistently underestimate the effect size. However, the Cox&Snell measure has been criticized because its range excludes 1. An adjustment was made to mitigate this situation, resulting in the Nagelkerke R^2 measure. Although none of the pseudo- R^2 measures could be interpreted strictly as the proportion of variance in the outcome explained by the predictors (as is the case for the R^2 in linear regression) (253), they are useful in that they provide a single numeric value that can be compared across models.

Assessing the contribution of individual variables:

The contribution of individual variables in a logistic regression model was evaluated using the Wald test and the likelihood-ratio test. Both tests are commonly used for the purpose and are described in detail in standard textbooks on logistic regression (253, 255, 258). The Wald test tests the null hypothesis that the regression coefficient is different from zero (255). The likelihood-ratio test tests the change in model fit when the predictor of interest is omitted from the model (253-255). The basis of the likelihood-ratio test was elaborated on previously. When the absolute value of the regression coefficient is large, its estimated standard error tends to be inflated when applying the Wald test, thereby increasing the risk of making a type II error (i.e., the test becomes too conservative) (259). The likelihood-ratio test does not suffer this flaw and is therefore often preferred when the tests yield different results (254, 258, 259). The computational power required was previously an issue when applying the likelihood-ratio test, but this becomes decreasingly relevant. For study purposes, both tests were used in conjunction, as this method presents the additional advantage of checking the sufficiency of sample size (inconsistency could be used as a screening tool for insufficient sample size) (257). The association between a predictor and the outcome is quantified in terms of the odds ratio. The odds ratio is the change in odds of belonging to one outcome category when the value of a

predictor increases by one unit. The regression coefficient (B) of a predictor is equal to the natural log of the odds ratio (i.e., odds ratio = e^B). Therefore, a change of one unit in a predictor multiplies the odds of the outcome by e^B (255, 256). The odds ratio is always interpreted in the context of a reference level.

Variable selection:

A common criticism in building multivariate models is that researchers do not always explain the modeling strategy applied (260). Most experts agree that a theoretical model based on relevant clinical knowledge and reasoning should forego the selection of variables to include in multivariate models. This is in contrast to systematically testing a large number of variables and including the set that produces the most interesting results (253, 261, 262). A common approach is to use the most parsimonious model that still has an acceptable explanatory value (262). These two principles permeated the modeling strategy in all study parts. More explicitly, the strategy followed these six steps:

- Creating the theoretical model
- Specifying the relevant variables to adjust for
- Screening data for missing values and fitting distributions
- Assessing confounding
- Assessing interaction
- Final selection of variables

The theoretical model was established through iterative discussions within the networks of the research group (consisting of ED staff, researchers and leadership). Variables were specified while establishing the theoretical model. Data were screened for missing values, outliers and normality before modeling. Before deciding whether to include a variable as a continuous predictor or not, the assumption of linearity in the logit was evaluated using the Box-Tidwell approach (253). If violated, variables were converted to the ordinal scale.

Confounding was addressed in the theoretical models, as well as using Directed Acyclic Graphs (DAGs), created *a priori* to the multivariate models. DAGs were also used in order to specify the minimally sufficient adjustment sets for each analysis and to limit endogenous selection bias (263-265). The freely available online tool DAGitty was used to construct the diagrams (266).

There is a tradeoff between the risk for introducing endogenous selection bias (by introducing more variables than is specified in the minimally sufficient adjustment set) and achieving face validity (i.e., a high explanatory value of the model). Face validity is an important feature of models testing the contribution of a predictor of interest (257), simply because a significant contribution of a variable in a model that poorly predicts the outcome is not very convincing. For the purposes of this

work, DAGs and theoretical models constituted the foundation, which was expanded through the use of variables (e.g., triage priority, sex, age) that were important for face validity but that were not proper confounders of the outcome.

Multicollinearity:

The first step in addressing multicollinearity in the multivariate models was to construct a correlation matrix for bivariate correlations between candidate variables. A Spearman correlation coefficient of 0.70 was used as the cutoff (267). During the modeling process, models were screened for multicollinearity by inspecting standard errors of regression coefficients along with model convergence (253). Multicollinearity was finally addressed by VIF and tolerance statistics, along with inspecting the condition index for each model (267, 268).

Power calculations:

In general, the sample size was not subject to additional restrictions in order not to introduce selection bias. *Post hoc* power calculations as proposed by Rosner (2011) were performed in order to address group size when converting continuous variables to the ordinal scale (269). *Post hoc* power analysis was also applied after calculations in order to address the power of the detected differences.

The initial work describing sample sizes in logistic regression relied heavily on the assumption of normality among the predictor variables (270). Since a common reason for using the method is the lack of assumptions about the distribution of included variables, researchers have requested alternate approaches. In an attempt to answer the question, Peduzzi (1996) conducted simulation studies that indicated that the regression coefficients were not severely biased at sample sizes allowing for 10 events or more per predictor (257, 271). The work has been frequently cited since, and 10 events per predictor is often used as a rule of thumb when determining sample size in logistic regression. However, the number of predictors allowed for in logistic regression is also influenced by other factors, such as effect size and multicollinearity. Another way of addressing whether insufficient sample size poses a problem to a model is to compare the consistency of results from the likelihood-ratio test and the Wald test of variable contribution. Comparison of the consistency of results across models has also been recommended (257). In an attempt to maintain a conservative strategy, all the factors above were addressed when assessing appropriateness of sample size.

Statistical analyses were performed in the Statistical Package for the Social Sciences® version 22 (IBM). Linking and concatenation of data were performed in the programming language Python™.

Ethical review

The Regional Ethical Review Board in Lund granted ethical approval for the study (dnr 2013/11).

Part I

Part I was conducted as a registry study on administrative data. It included all visits to the ED of a 420-bed emergency hospital in southern Sweden, registered in the ED information system Patientliggaren® between 1 January 2011 and 31 December 2012, not resulting in referral to another hospital. Visits to the separate EDs for pediatric medicine, psychiatry and obstetrics/gynecology were not included. The exposure (access block) was defined as strata of in-hospital bed occupancy at the time of patient presentation in the ED, beginning at 95% occupancy. The outcome was admission to hospital. The theoretical model is shown in the figure below. The minimally sufficient adjustment set to isolate the overall effect of exposure on the outcome, according to the DAG methodology, was: time of year, time of day and day of week. A 3% difference in the proportion admitted was considered clinically relevant for the purposes of this study.

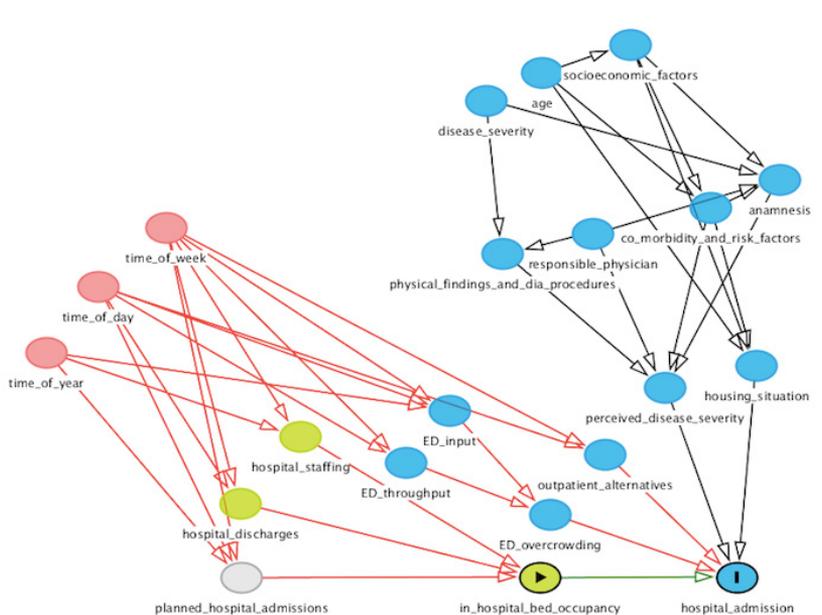


Figure 2.
Directed Acyclic Graph for hospital admission

Part II

Part II was conducted as a registry study/retrospective cohort study. The time for exposure and outcome were identified in the ED information system Patientliggaren®. The study population included all visits to the ED of a 420-bed emergency hospital in southern Sweden, between 1 January 2011 and 31 December 2012, which did not result in inpatient admission, death, or transfer to another hospital. The exposure (access block) was defined as strata of in-hospital bed occupancy at the time of patient index-presentation in the ED, beginning at 95% occupancy. A sensitivity analysis, making hospital occupancy of <85% the reference, was also conducted. The outcomes were unplanned 72h revisits to the ED and unplanned 72h revisits to the ED resulting in subsequent admission, respectively. The theoretical model is shown in the figure below. The minimally sufficient adjustment set to isolate the overall effect of the exposure on the outcome, according to the DAG methodology, was: time of year, time of day and day of week. A 2% difference in the proportion revisiting and 1% in the proportion revisiting and becoming admitted were considered clinically relevant for the purposes of this study.

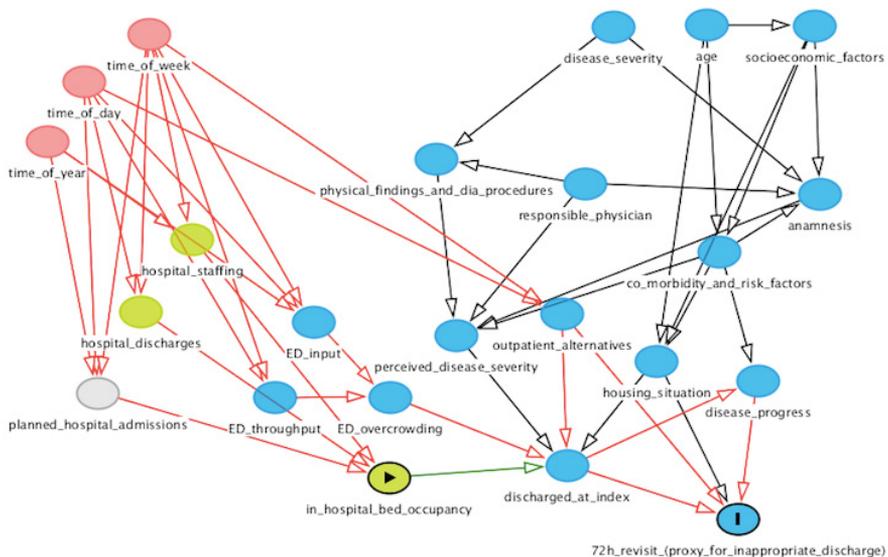


Figure 3.
Directed Acyclic Graph for unplanned 72h revisits

Part III

The main incentive for conducting Part III originated from the heterogeneity of the diversion effect/admission-bias detected in Part I, across groups of patients with different main complaints. Patients with acute abdominal pain were chosen, as this was the most common main complaint at the study site. The management strategies applied to this group of patients include early laparoscopy (EL), which is helpful in establishing a definitive diagnosis (272-274) but its associated risks make the net benefit of EL questionable (272, 275, 276). Some argue that clinical observation in the inpatient setting is comparable to EL (277). Likewise, radiology may improve diagnostic accuracy (278-281) and is generally available in EDs, but may expose patients to excessive radiation, even though low-dose protocols become increasingly available (282). Inpatient observation of patients with acute abdominal pain is common, but usually also involves the use of radiology (272, 276, 283).

Part III was conducted as a registry study/retrospective cohort study. The time for exposure and outcome were identified in the ED information system Patientliggaren®. The exposure (access block) was defined in terms of the in-hospital bed occupancy at the time of patient presentation in the ED. The outcomes were hospital admission and unplanned 72h revisits, resulting in subsequent admission and not. Revisits also included revisits to the ED of a nearby hospital. EDLOS was compared across levels of access block in patients discharged from the ED. Study subjects were patients with a main complaint of acute abdominal pain assessed at the surgical and emergency medicine (EM) specialty units in the ED of a 420-bed emergency hospital in southern Sweden, between 1 January 2011 and 31 December 2013. Cases below 18 years of age, cases who deceased in the ED, who left the ED against medical advice or were transferred to another hospital, were excluded. The minimally sufficient adjustment sets were similar to what was reported in conjunction with Parts I and II. Clinically relevant differences in outcomes were as reported in conjunction with Parts I and II.

Part IV

Another common main complaint in patients visiting the ED at the study site is chest pain. Chest pain is a symptom that can be indicative of life threatening underlying conditions, e.g. AMI or pulmonary embolism (PE). The advent of clinical decision rules (284, 285) and increasingly sensitive biomarkers (286-288), have decreased the time taken to rule out AMI over the last decades, but the condition frequently requires observation in excess of 4 hours (289). Therefore,

patients with chest pain are often admitted to inpatient wards for observation. The diagnosis of PE is generally more accessible to radiology than that of AMI.

Part IV was conducted as a registry study/retrospective cohort study. The time for exposure and outcome were identified in the ED information system Patientliggaren®. The exposure (access block) was defined in terms of the in-hospital bed occupancy at the time of patient presentation at the ED. The outcomes were hospital admission and unplanned 72h revisits, resulting in subsequent admission and not. Revisits also included revisits to the ED of a nearby hospital. EDLOS was compared across levels of access block in patients discharged from the ED. Study subjects were patients with a main complaint of chest pain assessed in the internal medicine and EM specialty units in the ED of a 420-bed emergency hospital in southern Sweden, between 1 January 2011 and 31 December 2013. Cases below 18 years of age, cases who deceased in the ED, who left the ED against medical advice or were transferred to another hospital, were excluded. The minimally sufficient adjustment sets were similar to what was reported in conjunction with Parts I and II. Clinically relevant differences in outcomes were as reported in conjunction with Parts I and II.

Part V

Part V was conducted as a registry study/retrospective cohort study. The time for exposure and outcome were identified in the ED information system Patientliggaren®. The exposure (access block) was defined in terms of in-hospital bed occupancy at the time of patient presentation in the ED. A sensitivity analysis, in which hospital occupancy was measured 3 hours prior to presentation, was also conducted. Study subjects were patients assessed in primary triage at the ED of a 420-bed emergency hospital in southern Sweden between 1 January 2011 and 31 December 2012. The minimally sufficient adjustment sets to isolate the overall effect of the exposure on the outcomes, according to the DAG methodology, were: ED input, time of day and day of week. A 3% difference in the proportion admitted and a 2% difference in the proportion revisiting were considered clinically relevant for the purposes of this study.

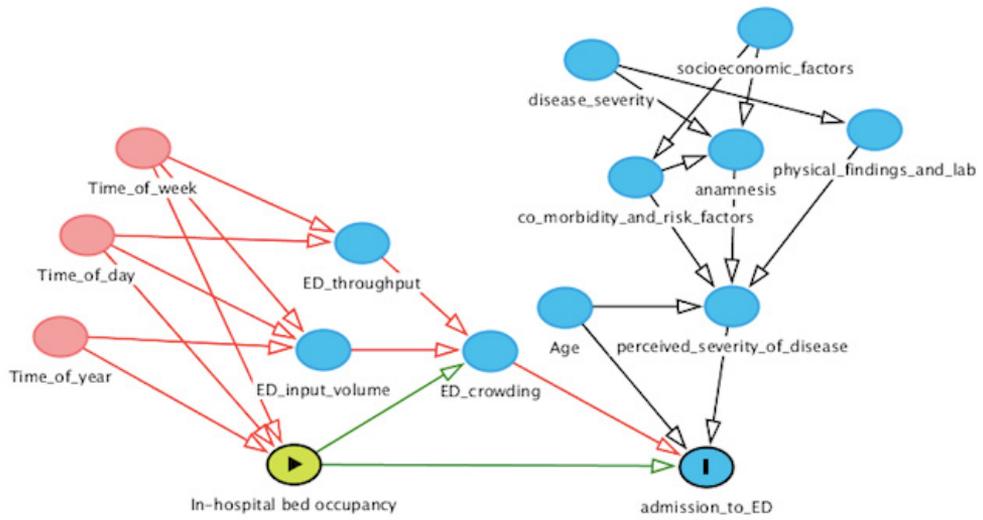


Figure 4. Directed Acyclic Graph for ED admission from primary triage

Results

Part I

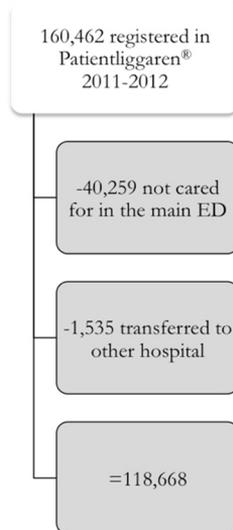


Figure 5.
Exclusion analysis

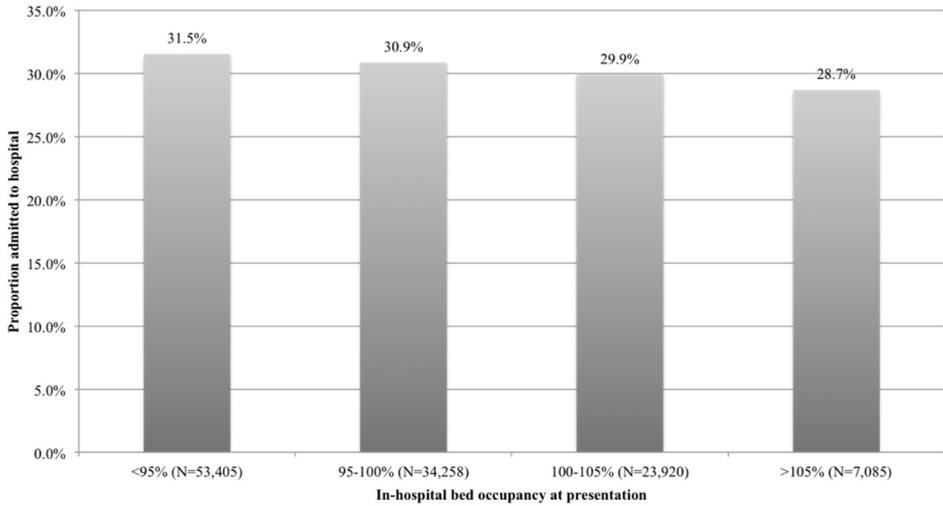


Figure 6. Proportion admitted to hospital, stratified by in-hospital bed occupancy

The crude proportion of patients admitted to hospital was lower at higher levels of in-hospital bed occupancy ($p<.0001$, χ^2). *Post hoc* power calculations revealed a study power $>99\%$ to detect the pre-specified differences.

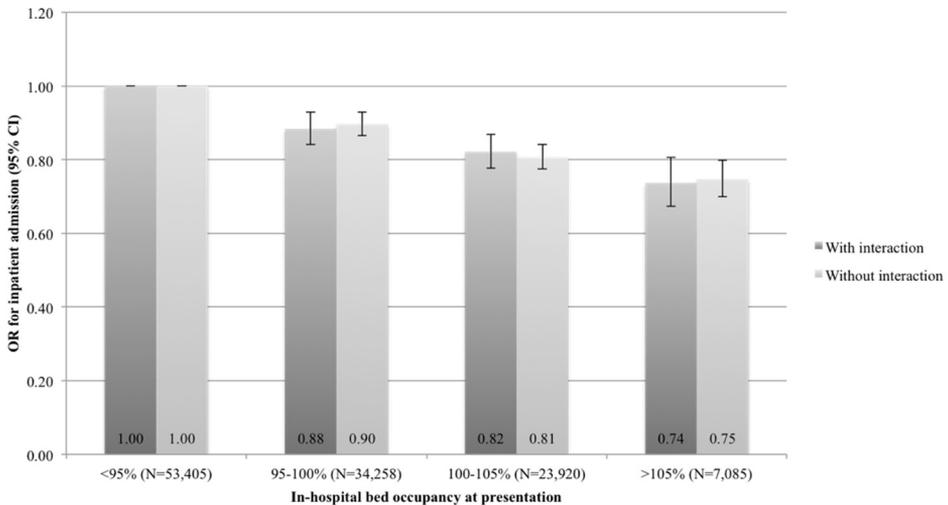


Figure 7. Odds ratio admission to hospital at different levels of in-hospital bed occupancy. <95% ref. Logistic regression. Nagelkerke's $R^2=0.37$

After adjusting for several factors, the multivariate model showed a negative association between in-hospital bed occupancy and the odds of inpatient admission. This supported the findings from the crude analysis. Being significantly associated with the outcome, the interaction term between in-hospital bed occupancy and the variable indicating the ten most common main complaints indicated that the magnitude of the effect was different for patients with different main complaints. The effect of the exposure on the outcome was isolated from the effects of: main complaint, age group (<18, 18-40, 40-65, >65 years), referral status, triage priority, presentation on a shift with high ED input, presentation during night shift (00:00-08:00), presentation during weekend, sex, LWBS, and admission to the ED via primary triage.

Table 2.

Odds ratio of admission to hospital from different specialty units, at different levels of hospital occupancy. <95% ref. NGK=Nagelkerke's R²

Specialty unit	Occupancy	Regr. coeff.	S.E.	Wald	<i>p</i>	OR	95% CI	
							lower	upper
Internal medicine (N=35,016) NGK=0.37	<95% (N=16,266)	Ref.	Ref.	58.19	<.001	Ref.	Ref.	Ref.
	95-100% (N=10,452)	-0.14	0.03	22.60	<.001	0.87	0.82	0.92
	100-105% (N=6,569)	-0.22	0.04	36.46	<.001	0.80	0.75	0.86
	>105% (N=1,729)	-0.33	0.06	29.86	<.001	0.72	0.64	0.81
Surgery (N=27,210) NGK=0.26	<95% (N=13,129)	Ref.	Ref.	28.67	<.001	Ref.	Ref.	Ref.
	95-100% (N=8,070)	-0.16	0.04	20.35	<.001	0.85	0.80	0.91
	100-105% (N=5,167)	-0.17	0.04	17.11	<.001	0.84	0.78	0.91
	>105% (N=1,344)	-0.17	0.07	6.10	.01	0.84	0.73	0.97
Orthopedics (N=27,600) NGK=0.42	<95% (N=12,880)	Ref.	Ref.	25.37	<.001	Ref.	Ref.	Ref.
	95-100% (N=7,930)	0.00	0.05	0.01	.94	1.00	0.91	1.11
	100-105% (N=5,251)	-0.26	0.06	18.62	<.001	0.77	0.68	0.87
	>105% (N=1,539)	-0.24	0.10	6.41	.01	0.78	0.65	0.95
Emergency medicine (N=16,740) NGK=0.36	<95% (N=6,391)	Ref.	Ref.	11.34	.01	Ref.	Ref.	Ref.
	95-100% (N=4,558)	-0.01	0.05	0.02	.90	0.99	0.90	1.10
	100-105% (N=4,296)	-0.03	0.05	0.41	.52	0.97	0.88	1.07
	>105% (N=1,495)	-0.25	0.08	10.60	<.001	0.78	0.68	0.91
Otolaryngology (N=11,602) NGK=0.29	<95% (N=4,739)	Ref.	Ref.	9.40	.02	Ref.	Ref.	Ref.
	95-100% (N=3,248)	0.00	0.12	0.00	.99	1.00	0.79	1.28
	100-105% (N=2,637)	-0.36	0.15	5.99	.01	0.70	0.53	0.93
	>105% (N=978)	-0.40	0.22	3.44	.06	0.67	0.44	1.02

The negative association between in-hospital bed occupancy and the odds of inpatient admission remained significant across all levels of exposure for the internal medicine and surgery specialty units. It was only significant at the highest level of occupancy (>105%) for the emergency medicine specialty unit.

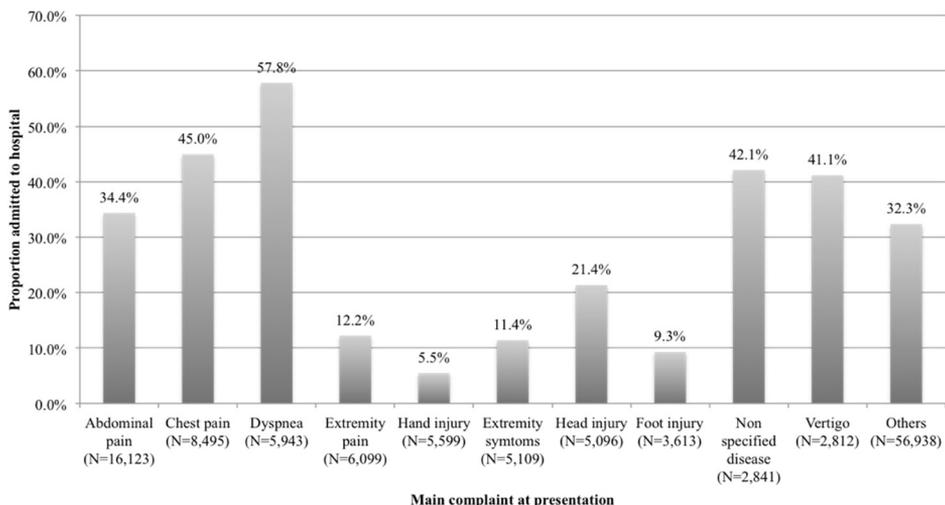


Figure 8.
Proportion admitted to hospital, stratified by ten most common main complaints

Acute abdominal pain and chest pain were the most common main complaints. Chest pain and dyspnea often resulted in inpatient admission, injured extremities less frequently so.

Table 3.
Descriptive data across the outcome of interest

Variable	Proportion admitted to hospital	Variable	Proportion admitted to hospital
Age [years]	<18 (N=16,381)	Triage priority	Prio 1 (N=5,689)
	18-40 (N=30,097)		Prio 2 (N=18,461)
	40-65 (N=33,468)		Prio 3 (N=63,828)
	>65 (N=38,722)		Prio 4 (N=28,502)
Referral status	Not referred (N=91,168)		Missing prio (N=2,188)
	Referred (N=18,667)		Sex
	Missing (N=8,833)	Female (N=58,567)	
Shift	08:00-16:00 (N=59,827)	Male (N=60,101)	
	16:00-00:00 (N=43,830)	LWBS (N=2,332)	
	00:00-08:00 (N=15,011)	Passed primary triage (N=18,616)	
		Total (N=118,668)	

Part II

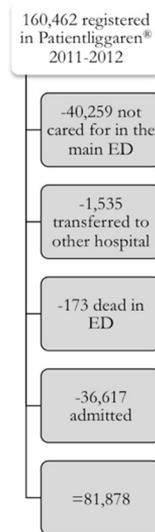


Figure 9.
Exclusion analysis

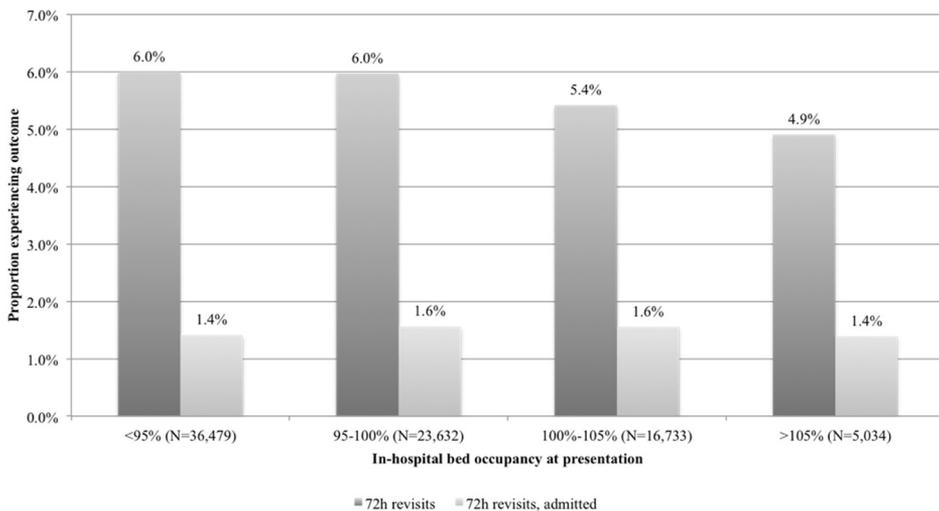


Figure 10.
Proportion of 72h revisits, stratified by in-hospital bed occupancy

Figure 10 shows that the proportion of patients who revisited the ED within 72 hours of being discharged was not positively associated with in-hospital bed occupancy. Rather, a negative association was detected in the crude analysis

($p=.001$, Fisher). *Post hoc* power calculations yielded a study power $>99\%$ to detect the pre-specified differences.

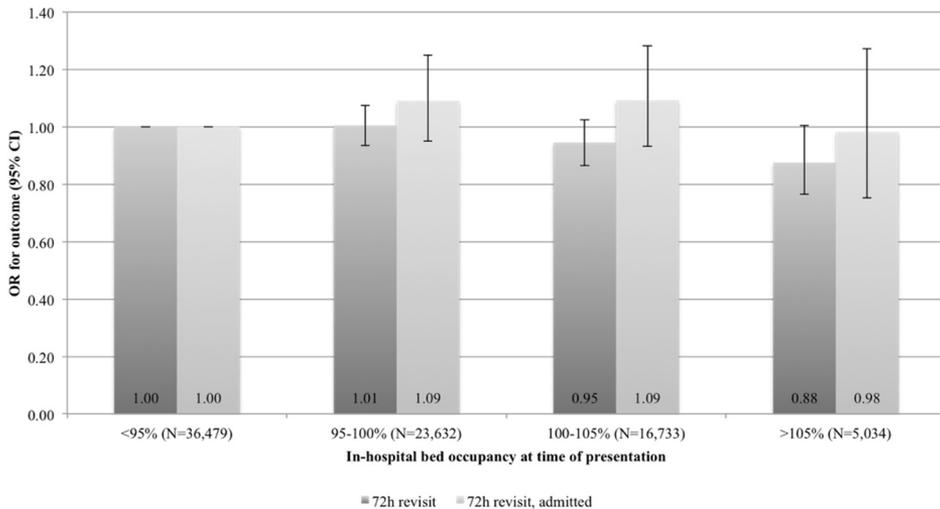


Figure 11.

Odds ratio of making a 72h revisit, at different levels of in-hospital bed occupancy. <95% ref. Logistic regression. Nagelkerke's $R^2=0.031$ (revisits) and 0.060 (revisits, admitted)

After adjusting for several factors, no significant association between in-hospital bed occupancy and the odds of making a 72h revisit was revealed. The same held true for 72h revisits resulting in admission. This supported the findings from the crude analysis. The odds ratio of making a revisit approached statistical significance for patients discharged at in-hospital bed occupancy of $>105\%$ compared to patients discharged at occupancy of $<95\%$ (95% CI for OR 0.76-1.01). The effect of exposure on the outcome was isolated from the effects of: ED specialty unit, main complaint, age group (<18 , 18-40, 40-65, >65 years), referral status, triage priority, presentation on a shift with high ED input, presentation during a night shift (00:00-08:00), presentation during a weekend, sex, LWBS, and admission to the ED via primary triage.

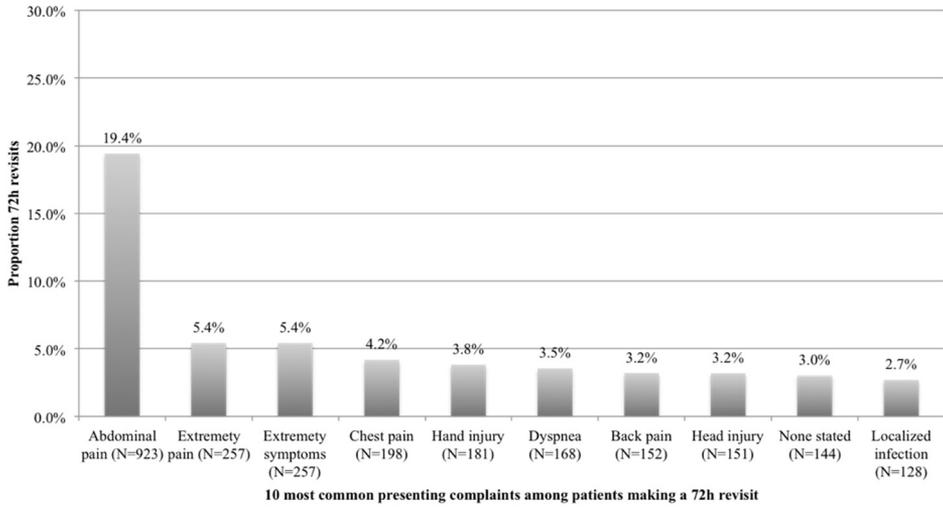


Figure 12.

Ten most common main complaints among patients making an unplanned 72h revisit. N=4,753

As seen in Figure 12, the most common index main complaint in patients revisiting the ED within 72 hours was abdominal pain.

Table 4.
Descriptive data across outcomes of interest

Variable		72h revisits	72h revisits, admitted	Variable		72h revisits	72h revisits, admitted
Discharging specialty unit	Internal medicine (N=18,340)	6.0%	1.8%	Triage priority	Prio 1 (N=1,161)	5.9%	2.3%
	Surgery (N=18,594)	7.6%	2.3%		Prio 2 (N=7,818)	7.1%	2.7%
	Orthopaedics (N=23,484)	4.4%	0.7%		Prio 3 (N=46,323)	5.9%	1.5%
	Otolaryngology (N=9,886)	5.8%	0.9%		Prio 4 (N=25,205)	5.0%	1.0%
	Emergency medicine (N=11,574)	5.5%	1.6%		Missing prio (N=1,371)	11.6%	2.3%
Shift	08:00-16:00 (N=42,202)	5.0%	1.7%	LWBS	(N=2,332)	14.7%	2.2%
	16:00-00:00 (N=30,354)	6.5%	1.4%		Sex	Female (N=40,281)	5.4%
	00:00-08:00 (N=9,322)	7.3%	1.5%	Male (N=41,597)		6.2%	1.6%
Age [years]	<18 (N=14,379)	5.0%	0.8%	Referral status	Not_referred (N=63,275)	5.8%	1.5%
	18-40 (N=25,242)	5.5%	1.1%		Referred (N=13,175)	4.2%	1.2%
	40-65 (N=24,298)	6.0%	1.5%		Missing (N=5,428)	10.1%	1.8%
	65- (N=17,959)	6.7%	2.6%	Total	(N=81,878)	5.8%	1.4%

14.7% of LWBS patients revisited within 72 hours, and 2.2% revisited within 72 hours and were admitted. This could indicate that some LWBS patients may have suffered from not entirely benign conditions.

Part III

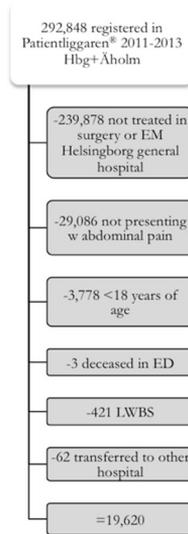


Figure 13.
Exclusion analysis

Table 5.
Descriptive data across outcomes of interest

Variable		Admitted	72h revisits	72h rev. adm.	Variable		Admitted	72h revisits	72h rev. adm.
Age [years]	18-40 (N=7,388)	25.5%	8.8%	2.9%	Triage priority	Prio 1 (N=293)	73.7%	12%	4%
	40-65 (N=6,733)	35.5%	9.2%	3.3%		Prio 2 (N=2,848)	62.2%	12.3%	5.8%
	65-80 (N=3,741)	51.0%	9.5%	4.0%		Prio 3 (N=14,199)	34.7%	9.1%	3.3%
	>80 (N=1,758)	66.3%	8.8%	5.6%		Prio 4 (N=2,197)	19.1%	6.5%	1.9%
				Missing (N=83)		16.9%	7%	3%	
Day of week	Mon (N=3,315)	38.5%	8.8%	3.0%	Through primary triage	08:00-16:00 (N=7,035)	36.8%	7.6%	2.9%
	Tue-Fri (N=11,448)	37.4%	9.0%	3.3%		16:00-00:00 (N=3,666)	38.7%	10.0%	3.5%
	Sat-Sun (N=4,857)	36.8%	9.4%	3.6%		00:00-08:00 (N=8,919)	36.7%	10.9%	4.2%
Sex	Male (N=7,905)	40.6%	11.1%	4.6%					
	Female (N=11,715)	35.4%	7.8%	2.6%					

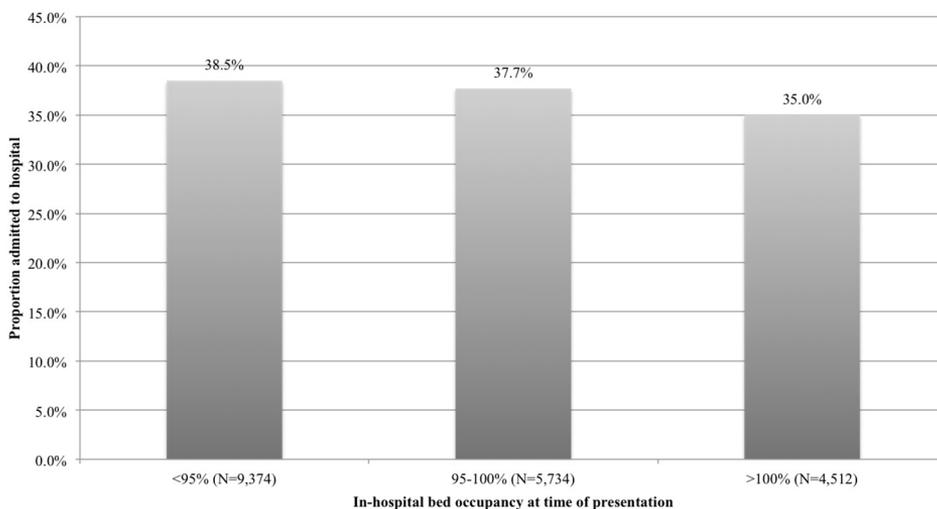


Figure 14.
Proportion of patients with abdominal pain that are admitted to hospital, stratified by in-hospital bed occupancy

The total proportion of inpatient admissions was 37.5%. The proportion admitted was negatively associated with in-hospital bed occupancy ($p=.001$, Fisher) in the crude analysis. *Post hoc* power calculations revealed a study power of $>90\%$ to detect the pre-specified difference.

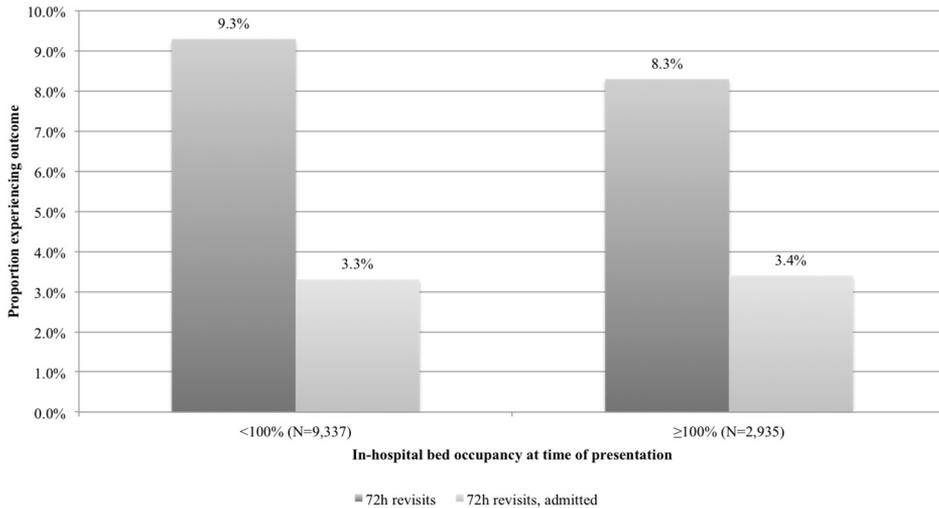


Figure 15.

Proportion of 72h revisits in patients with abdominal pain, stratified by in-hospital bed occupancy. N=12,272

The overall proportion of unplanned 72h revisits among the discharged patients was 9.0%. The corresponding number for unplanned 72h revisits resulting in inpatient admission was 3.3%. No significant association between the exposure and these two outcomes was revealed in the crude analysis ($p=.141$ and $p=.910$, Fisher). *Post hoc* power calculations revealed a study power of 87.7% and 71%, respectively, to detect the pre-specified differences.

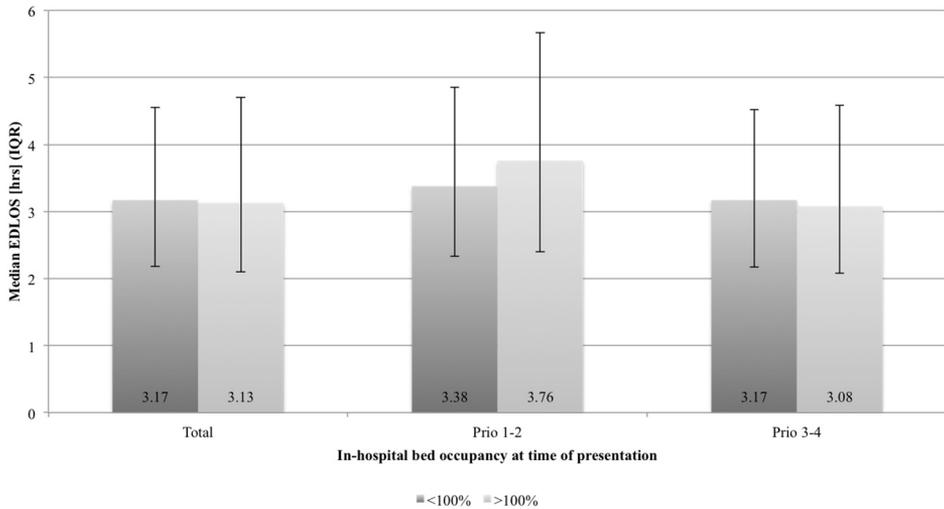


Figure 16. Median EDLOS at different levels of in-hospital bed occupancy, stratified by triage priority

Median EDLOS was significantly longer at occupancy $\geq 100\%$ compared to an occupancy $< 100\%$, for patients of triage priority 1-2, but not in total or for patients of triage priority 3-4 ($p=.26$, $.01$ and $.23$, respectively, Mann-Whitney U). *Post hoc* power calculations revealed that the study power for the detected difference was 78.6%.

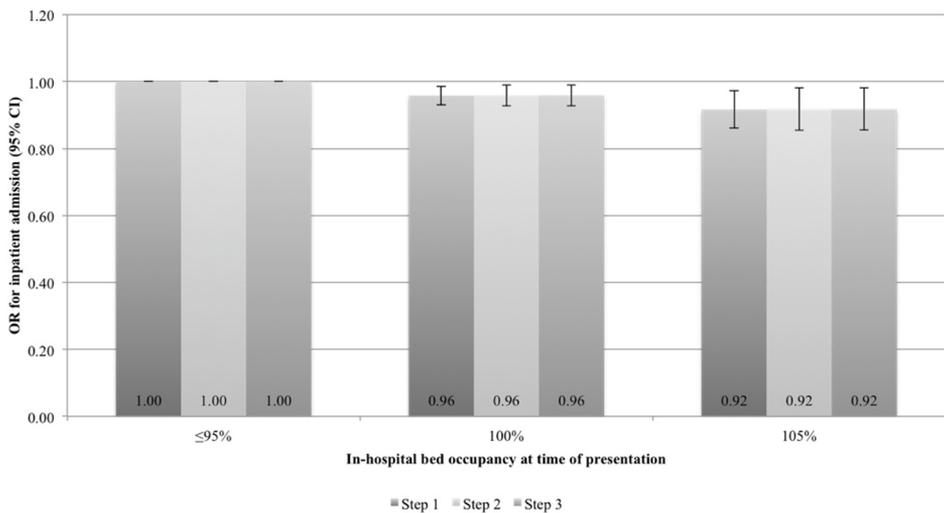


Figure 17. Odds ratio of admission to hospital at different levels of in-hospital bed occupancy. $< 95\%$ ref. Logistic regression. Steps 1-3

After adjusting for several factors, the multivariate model revealed a negative association between in-hospital bed occupancy and the odds of hospital admission. No association was found between the exposure and the other two outcomes. This supported the findings from the crude analysis. The effect of the exposure on the outcome was isolated from the effects of: time of day (00:00-08:00, 08:00-16:00, 16:00-00:00), day of week (Mon, Tue-Fri, Sat-Sun), time of year (Jun-Aug, Dec-Feb vs remainder) in step 1, with triage priority, sex, age group (18-40, 40-65, 65-80, >80 years) added in step 2, and admitted to the ED via primary triage, presence of EDOU and presentation on a shift with high ED input added in step 3. The analysis of 72h revisits excluded triage priority, whether the patient entered the ED via primary triage, and whether the patient presented during a shift with high input. The stability of the results across models of increasing explanatory value supported the findings. The presence of empty cells at the extremes of the hospital occupancy range suggested that the model was most reliable in the interval of occupancy 85%-105%.

Table 6.

Odds ratio of relevant outcomes, per percent increase in in-hospital bed occupancy. Adjustment sets 1-3 (NGK=Nagelkerke's R²)

Model		Regr. coeff.	S.E.	Wald	<i>p</i>	OR	95% CI	
							lower	upper
Inpatient admission	Step 1 (NGK=0.00)	-0.008	0.003	8.612	.003	0.992	0.986	0.997
	Step 2 (NGK=0.15)	-0.008	0.003	6.401	.011	0.992	0.985	0.998
	Step 3 (NGK=0.16)	-0.008	0.003	6.394	.011	0.992	0.986	0.998
72h revisit	Step 1 (NGK=0.01)	0.005	0.006	0.714	.398	1.005	0.993	1.017
	Step 2 (NGK=0.01)	0.005	0.005	0.683	.409	1.005	0.994	1.015
	Step 3 (NGK=0.01)	0.005	0.005	0.906	.341	1.005	0.995	1.016
72h revisit, admitted	Step 1 (NGK=0.00)	0.003	0.009	0.099	.753	1.003	0.985	1.022
	Step 2 (NGK=0.02)	0.002	0.008	0.105	.745	1.002	0.988	1.018
	Step 3 (NGK=0.02)	0.003	0.007	0.180	.671	1.003	0.989	1.017

Part IV

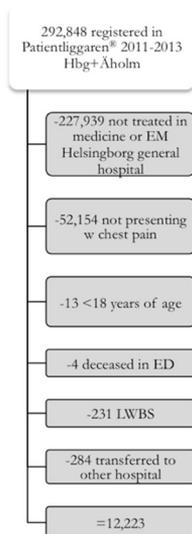


Figure 18.
Exclusion analysis

Table 7.
Descriptive data across outcomes of interest

Variable	Admitted	72h rev.	72h rev. adm.	Variable	Admitted	72h rev.	72h rev. adm.		
Age [years]	18-40 (N=2,133)	12.8%	3.1%	0.5%	Triage priority	Prio 1 (N=401)	87.5%	6%	2%
	40-65 (N=4,812)	38.3%	4.6%	1.4%		Prio 2 (N=3,854)	63.6%	5.0%	2.0%
	65-80 (N=3,365)	58.5%	4.7%	1.8%		Prio 3 (N=7,408)	34.1%	3.8%	1.1%
	>80 (N=1,913)	70.2%	3.5%	1.9%		Prio 4 (N=523)	16.4%	4.3%	2%
Mon (N=1,208)	42.3%	4.1%	1.7%	Missing (N=37)		29.7%	8%	0%	
Day of week	Tue-Fri (N=3,859)	45.4%	4.0%	1.2%	Through primary triage	08:00-16:00 (N=2,918)	45.8%	3.2%	1.1%
	Sat-Sun (N=1,729)	43.6%	4.3%	1.2%		16:00-00:00 (N=2,631)	40.1%	5.0%	1.6%
	Sex	Male (N=6,595)	47.5%	4.8%		1.7%	00:00-08:00 (N=1,247)	49.1%	4.4%
Female (N=5,628)		40.8%	3.4%	0.9%		(N=907)	19.0%	4.1%	1.0%

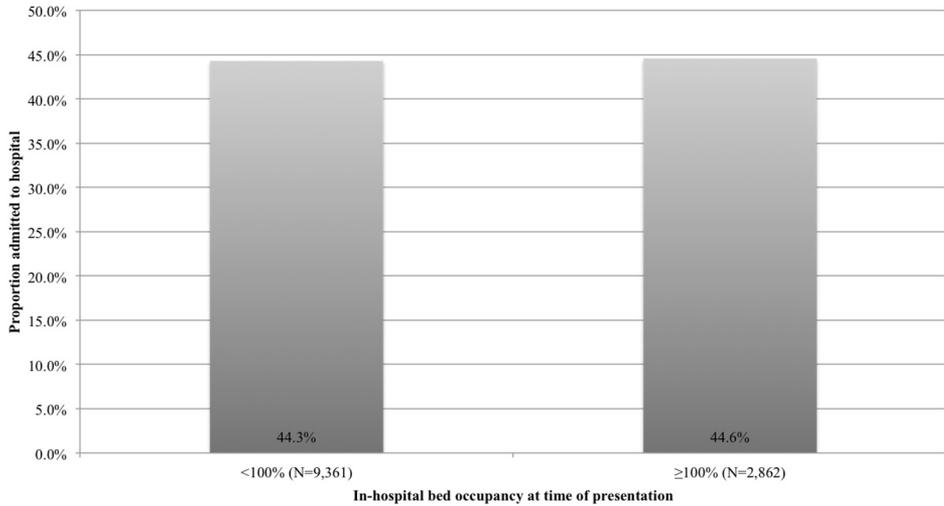


Figure 19. Proportion of patients with chest pain admitted to hospital, stratified by in-hospital bed occupancy

The total proportion of inpatient admissions was 44.4%. No significant association between in-hospital bed occupancy and inpatient admission was observed in the crude analysis ($p=.797$, Fisher). *Post hoc* power calculations revealed a study power of >80% to detect the pre-specified difference.

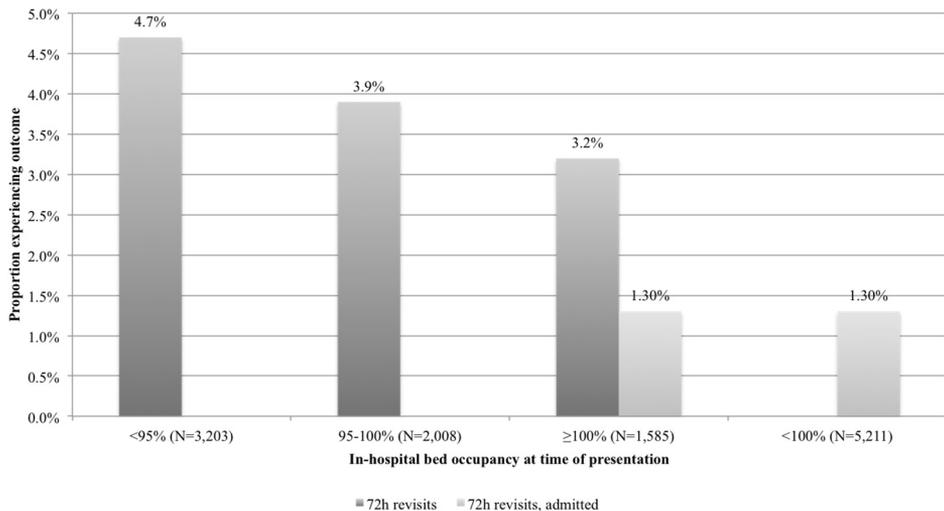


Figure 20. Proportion of 72h revisits, stratified by in-hospital bed occupancy, N=6,796

The overall proportion of unplanned 72h revisits among the discharged patients was 4.1%. The corresponding number for unplanned 72h revisits resulting in

inpatient admission was 1.3%. In the crude analysis, in-hospital bed occupancy at the time of presentation was negatively associated with 72h revisits ($p=.033$, Fisher) but not with 72h revisits resulting in admission ($p=.899$, Fisher). *Post hoc* power calculations revealed a study power of 87.8% and 77.6%, respectively, to detect the pre-specified differences.

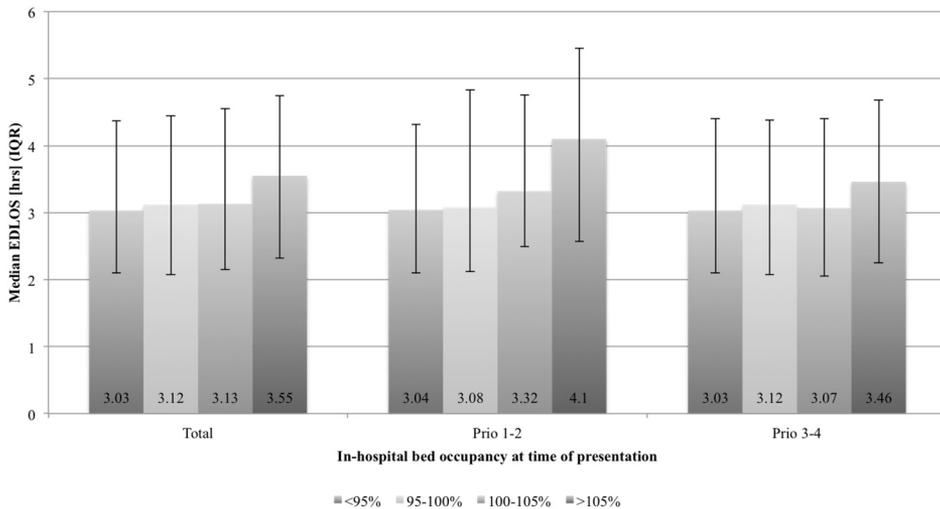


Figure 21. Median EDLOS at different levels of in-hospital bed occupancy, stratified by triage priority

Median EDLOS was significantly longer at increasing levels of occupancy for the entire group and for patients of triage priority 1-2 ($p<.01$, Kruskal-Wallis), but not for patients of triage priority 3-4 ($p=.114$, Kruskal-Wallis). *Post hoc* power calculations revealed that the study power for the detected differences was $>85\%$.

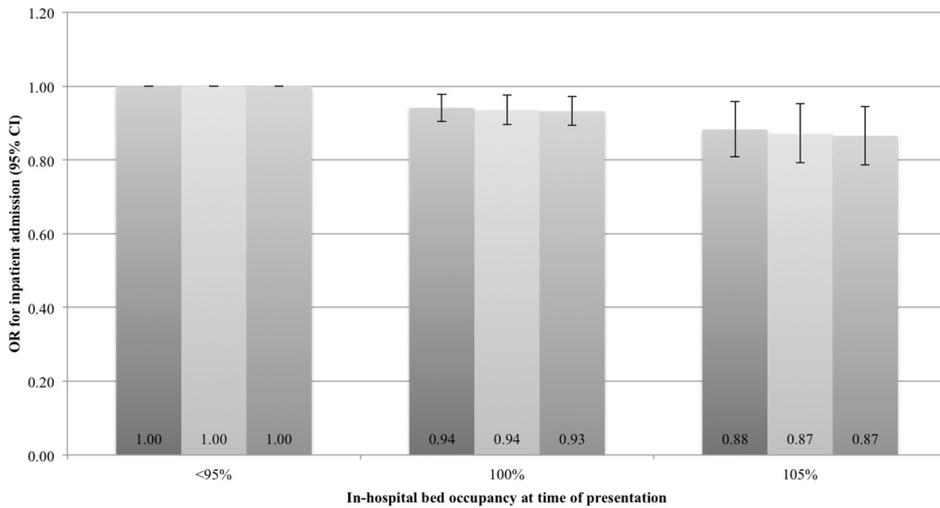


Figure 22.

Odds ratio of admission to hospital at different levels of in-hospital bed occupancy. <95% ref. Logistic regression. Steps 1-3

After adjusting for several factors, the multivariate model showed a negative association between in-hospital bed occupancy and the odds of inpatient admission. This supported the findings from the crude analysis. The effect of the exposure on the outcome was isolated from the effects of: time of day (00:00-08:00, 08:00-16:00, 16:00-00:00), day of week (Mon, Tue-Fri, Sat-Sun), time of year (Jun-Aug, Dec-Feb vs remainder) in step 1, with triage priority, sex, age group (18-40, 40-65, 65-80, >80 years) added in step 2, and admitted to the ED via primary triage, presence of EDOU, and presentation on a shift with high ED input added in step 3. The analysis of 72h revisits excluded triage priority, whether the patient entered the ED via primary triage, and whether the patient presented during a shift with high input. The number of events for 72h revisits resulting in admission was <10 for the adjustment sets specified in steps 2 and 3; hence, only step 1 of the multivariate analysis was pursued for this outcome. The stability of the results across models of increasing explanatory value supports the findings.

Table 8.

Odds ratio of relevant outcomes, per percent increase in in-hospital bed occupancy. Adjustment sets 1-3 (NGK=Nagelkerke's R²)

Model		Regr. coeff.	S.E.	Wald	<i>p</i>	OR	95% CI	
							lower	upper
Inpatient admission	Step 1 (NGK=0.01)	-0.012	0.004	9.425	.002	0.988	0.981	0.996
	Step 2 (NGK=0.27)	-0.013	0.004	9.643	.002	0.987	0.979	0.995
	Step 3 (NGK=0.29)	-0.014	0.004	10.823	.001	0.987	0.979	0.995
72h revisit	Step 1 (NGK=0.01)	-0.016	0.010	2.499	.114	0.984	0.964	1.004
	Step 2 (NGK=0.02)	-0.017	0.008	4.805	.028	0.983	0.968	0.998
	Step 3 (NGK=0.02)	-0.017	0.007	5.374	.020	0.983	0.969	0.997
72h revisit, admitted	Step 1 (NGK=0.01)	0.010	0.014	0.549	.459	1.011	0.983	1.039

The odds of making an unplanned 72h revisit were negatively associated with the in-hospital bed occupancy at patient presentation in the ED in steps 2 and 3 of the multivariate models. No association between the exposure and the odds of making a 72h revisit resulting in admission was observed.

Part V

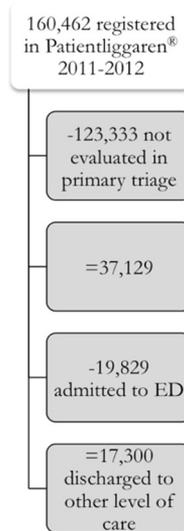


Figure 23.
Exclusion analysis

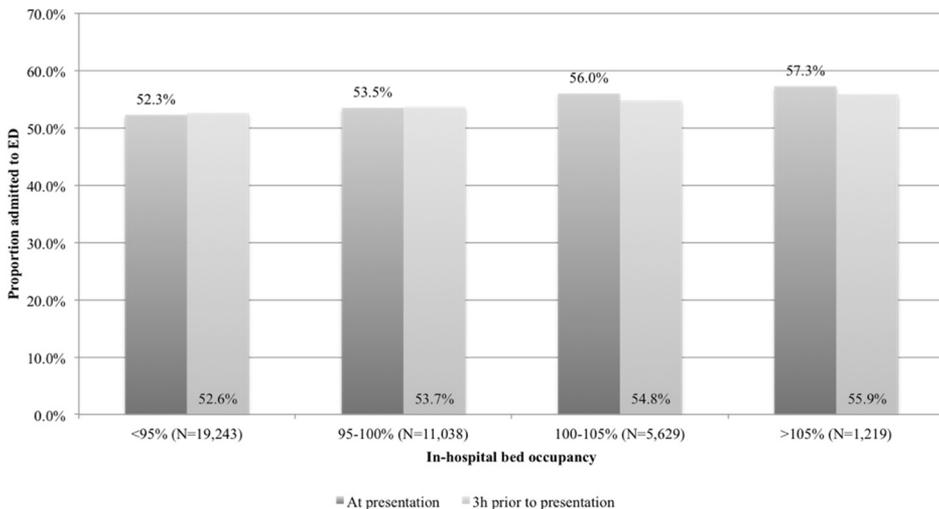


Figure 24.
Proportion of patients assessed in primary triage that were admitted to the ED, stratified by in-hospital bed occupancy

The total proportion of admissions to the ED was 53.4%. The proportion admitted to the ED was positively associated with in-hospital bed occupancy in the crude analysis, both when measured at presentation ($p < .001$, Fisher) and 3 hours prior to

presentation ($p=.003$, Fisher). *Post hoc* power calculations revealed a study power of $>90\%$ to detect the pre-specified difference.

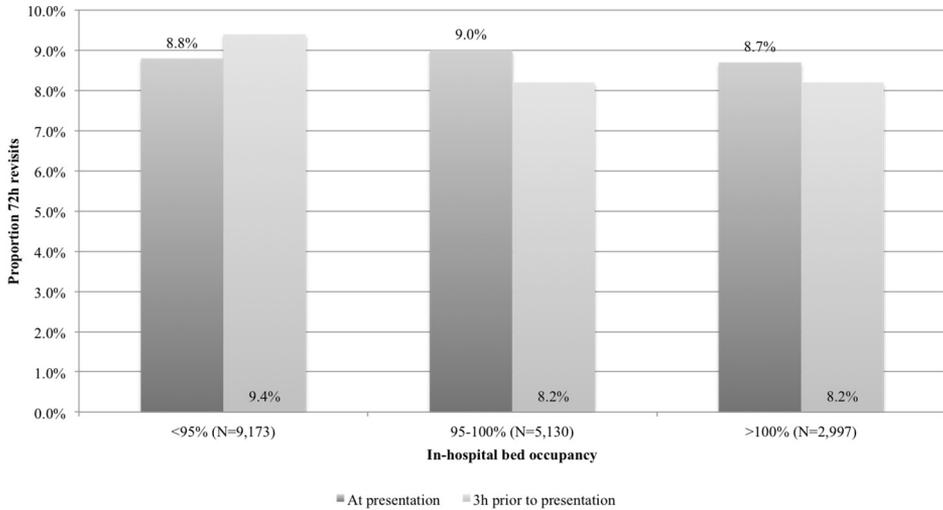


Figure 25.

Proportion of 72h revisits to the ED, stratified by in-hospital bed occupancy. N=17,300

The overall proportion of unplanned 72h revisits among the discharged patients was 8.8%. The proportion revisiting the ED within 72 hours was negatively associated with in-hospital bed occupancy ($p=.02$, Fisher) when measured 3 hours prior to presentation, but not when measured at the time of presentation ($p=.885$, Fisher). *Post hoc* power calculations revealed a study power of $>89\%$ to detect the pre-specified differences.

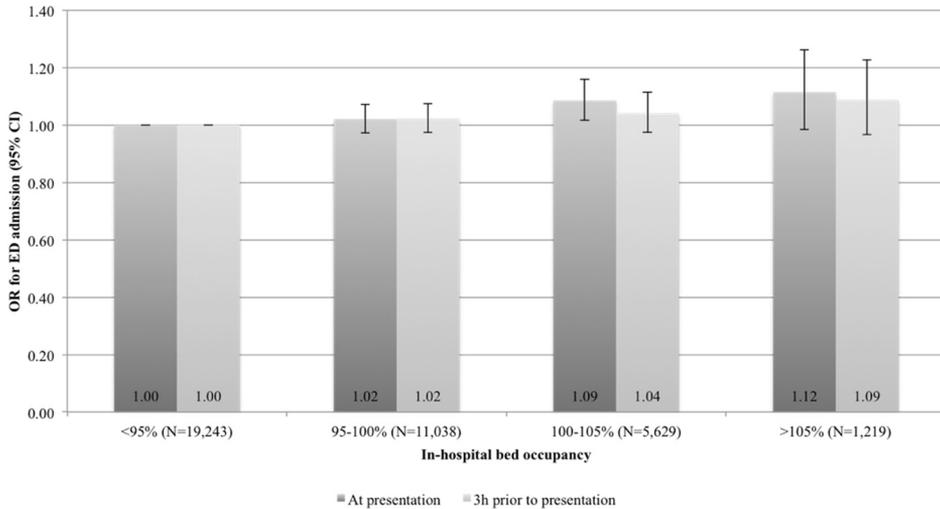


Figure 26.

OR for ED admission, for different levels of in-hospital bed occupancy <95% ref. N=37,129. Nagelkerke's $R^2=0.026$ (for both models)

After adjusting for several factors, the multivariate model showed no significant negative association between in-hospital bed occupancy and the odds of admission to the ED. However, a small positive association between in-hospital bed occupancy measured at patient presentation and admission to the ED was observed for occupancy 100-105% compared to <95% (95% CI for OR 1.02-1.16). The increased permeability of primary triage observed in the crude analysis was much attenuated in the adjusted analysis. The effect of the exposure on the outcome was isolated from the effects of: sex, age group (0-1 year, 1-18 years, 18-40 years, 40-70 years and ≥ 70 years), shift (00:00-08:00, 08:00-16:00, 16:00-00:00), day of week (Mon, Tue-Fri, Sat-Sun), registration by a spot-check nurse (rather than a secretary) upon arrival, presentation on a shift with high primary triage input and presentation on a shift with high ED input.

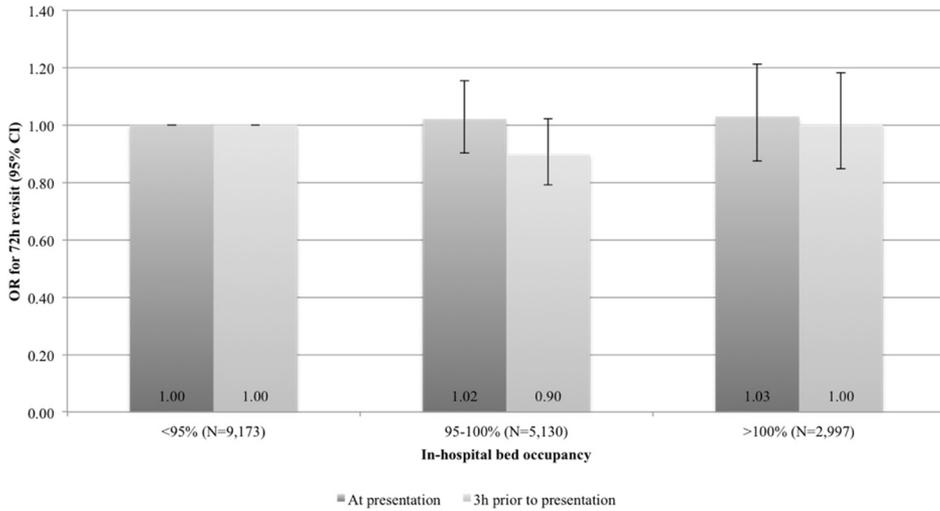


Figure 27.

OR for 72h revisit, for different levels of in-hospital bed occupancy <95% ref. N=17,300. Nagelkerke's $R^2=0.016$ (occ. measured at presentation) and 0.017 (occ. measured 3h prior to presentation)

After adjusting for several factors, no significant association between in-hospital bed occupancy and the odds of making a 72h revisit was revealed. The effect of the exposure on the outcome was isolated from the effects of: sex, age group (0-1 year, 1-18 years, 18-40 years, 40-70 years and ≥ 70 years), shift (00:00-08:00, 08:00-16:00, 16:00-00:00), day of week (Mon, Tue-Fri, Sat-Sun), registration by a spot-check nurse (rather than a secretary) upon arrival, presentation on a shift with high primary triage input and presentation on a shift with high ED input.

Table 9.
Proportion of cases experiencing each outcome

Variable			Variable			
ED admission (N=37,129)			ED admission (N=37,129)			
72h revisits (N=17,300)			72h revisits (N=17,300)			
Age [years]	<1 (N=177)	53.7%	3.7%	08:00-16:00 (N=13,716)	54.7%	7.4%
	1-18 (N=6,573)	53.9%	7.6%	16:00-00:00 (N=17,361)	51.0%	8.4%
	18-40 (N=15,756)	47.5%	8.3%	00:00-08:00 (N=6,052)	57.3%	13.5%
	40-70 (N=12,043)	57.9%	10.1%	Monday (N=5,348)	52.5%	8.4%
	>70 (N=2,580)	67.4%	11.3%	Tue-Fri (N=18,482)	54.0%	8.5%
Year	2011 (N=19,974)	55.2%	9.4%	Weekend (N=13,299)	53.0%	9.5%
	2012 (N=17,155)	51.3%	8.2%	Total (N=37,129)	53.4%	8.8%

Discussion

Part I

The results reported in Part I suggested that ED patients were less likely to be admitted to a hospital bed at times of access block. The effect was more pronounced at higher levels of access block and remained after adjusting for several factors, such as main complaint, disease severity, age and sex. The significance of the interaction term between hospital occupancy and the most common main complaints in the study population suggested that the effect was not constant for patients with different main complaints. This appeals to logic, since some main complaints could be suggestive of more severe or rapidly progressing disease, which more often required inpatient admission. It is likely that the findings reflect an admission-bias, where only the sickest patients were admitted to the hospital at times of access block. The findings are supported by other reports suggesting that physicians try to reduce inpatient admissions when few inpatient beds are available (213, 290). The findings may not be generalizable to all settings. For example, the admission bias was not detected in an Australian study of three metropolitan hospitals (37). Even though the results in part I suggested that ED patients were less likely to be admitted to the hospital at times of access block, the study did not address whether the effect indicated increased risk taking among ED staff or whether “unnecessary” inpatient admissions were averted as a result of more thorough evaluation and treatment in the ED.

Methodological considerations:

The main limitation of the study concerned its external validity, which is an issue in all single-center studies. Through the investigation of the undifferentiated ED population, rather than certain groups of patients, we hoped to mitigate some of these effects. The absence of information-system crashes during the study period should have limited differential misclassification and information bias.

Part II

Part II was designed in an attempt to answer the question of whether ED discharges made at times of access block were less appropriate than discharges made at other times. The outcome measure was unplanned 72h revisits to the ED, mainly because it was appointed a national-level quality indicator for emergency care in Sweden in 2013. Crude results revealed a decreased proportion of 72h revisits in patients discharged at times of access block, compared to patients discharged otherwise. No significant association between access block and the probability of making an unplanned 72h revisit was revealed after adjusting for several factors in a multivariate model. The sensitivity analysis conducted made use of a lower level of in-hospital bed occupancy as reference category (<85%), in order to capture possible mechanisms induced at lower levels of access block. The sensitivity analysis did not reveal any significant associations between the exposure and the outcome, either. The overall proportion of unplanned 72h revisits of 5.8% was somewhat higher than the 1.4% to 5.5% described in other studies (291-295). The same holds true for the 1.5% of discharged cases who made an unplanned revisit resulting in admission (292, 293). The proportion of revisits and revisits resulting in admission among LWBS cases (14.7% and 2.2% respectively) were also higher than what has been reported elsewhere (74, 76, 86, 87), which suggested that the underlying conditions in this patient population may not have been entirely benign. Several causal relationships could account for the decrease in 72h revisits observed in the crude analysis; e.g., discharge planning that included follow-up in primary care or in a hospital department (e.g., orthopedics), or revisits to other EDs in the region. The latter is probably less common at the study site than in urban US settings, due to limited overlap in ED catchment areas. However, an increased proportion of patients dying shortly after ED discharge would yield a similar statistical pattern. Even though the absence of an increase in 72h revisit suggest that discharges made at times of access block were no more inappropriate than discharges made otherwise on the macro level, the outcome measure failed to identify mortality and other rare (but fatal) outcomes. Most studies concerned with admission-biases in the context of access block have reported increased mortality rates in patients admitted to hospital, but few address outcomes in patients discharged from the ED. However, Guttmann (2011) reported an increase in outpatient mortality within 7 days of discharge from the ED (95% CI for OR 1.24-2.35) among cases discharged during ED overcrowding. The study exposure differed from that in the present study, as it was quantified by ED waiting times, rather than hospital bed occupancy (36).

Methodological considerations:

Future studies should address mortality and other rare but severe outcomes, in order to clarify the safety aspects of the admission-bias further. Moreover, it may

be of interest to address changes in case management within the ED, such as changed use of radiology or lab tests. Such knowledge would allow for subsequent cost-effectiveness analyses of managing patients in the ED as an alternative to inpatient admission. To the author's knowledge, few such analyses exist today, but cutting cost through reducing the number of inpatient beds remains common practice in many healthcare systems globally. The explanatory value of the multivariate models developed in Part II indicated that significant predictors of 72h revisits were omitted from the models (e.g. housing situation, co-morbidity). This would have been more relevant if the aim of the study was to predict who would revisit the ED, rather than to evaluate the effect of a particular predictor of interest, as was the case. The sensitivity analysis was less stable than the main analysis from a methodological viewpoint, as the reference category contained relatively few cases.

Part III

Part III revealed that also the patients who presented with acute abdominal pain were less likely to be admitted to a hospital bed, at times of access block than otherwise. The effect appeared somewhat attenuated when compared to the undifferentiated ED population studied in Part I. ED discharges were no more inappropriate at times of access block than otherwise, as measured by 72h revisits. However, this outcome did only capture macro level patterns and said nothing about rare (but fatal) outcomes such as mortality. The positive association between in-hospital bed occupancy and EDLOS in patients of triage priority 1–2 who were ultimately discharged from the ED could be interpreted as support for the hypothesis of their being subject to more evaluation and/or treatment in the ED at times of access block. For example through increasing use of radiology to rule out time-sensitive underlying conditions. However, it could also be indicative of longer waiting times for diagnostics and treatment in the ED. Given that some of the underlying conditions in the patient population are time-sensitive, this could be of detriment to patients. Future studies should include more granular endpoints (such as mortality) in the patients discharged from the ED, as well as more detailed data about which procedures and interventions were performed in the ED, in order to clarify the safety aspects of the effect. Such studies would allow for answering the question about whether the observed admission-bias was an expression of increased risk taking by ED staff (through discharging sick patients home) or if a larger proportion of patients received necessary evaluation and treatment in the ED and that unnecessary inpatient admissions thereby were averted, at times of access block.

Methodological considerations:

Part III captured more revisits than did Part II, as it also included revisits to a nearby hospital. The study covered a longer time-period (2011-2013), than did Parts I and II. Downsizing of inpatient bed capacity in 2013 may have resulted in new management strategies taking effect, which could have impacted the results. The direction of such bias would be towards decreased rates of inpatient admission, attenuating the observed admission-bias. Patients <18 years of age were not included in the study. This affects the generalizability of results to a large group of patients presenting with abdominal pain: children with appendicitis. Future studies should include more hospitals in order to improve the external validity of the results and increase statistical power to a level that allows for more thorough subgroup analysis.

Part IV

The results of Part IV revealed that patients who presented at the ED with chest pain were less likely to be admitted to a hospital bed at times of access block, just as was the case for the undifferentiated ED population in Part I and the patients with acute abdominal pain in Part III. As in patients with acute abdominal pain, the association was weaker than for the undifferentiated ED population at the study site. The significantly longer EDLOS observed at times of access block may reflect that ED staff increasingly performed necessary evaluation and treatment in the ED, in order to avert hospital admissions. Examples could be patients waiting for cardiac enzymes or a CT scan of the pulmonary circulation in the ED, rather than in the inpatient setting. However, the increased EDLOS could also reflect longer waiting times for diagnostics and treatment in the ED, and given that some of the underlying conditions in the patient population are time-sensitive, this could be of detriment to patients. The decreased revisit rate observed could either be explained by alternative management strategies, where time-sensitive conditions were ruled out and ED staff arranged suitable follow-up appointments that reduced the need for subsequent ED visits, or by that patients sought care at other facilities than the two EDs captured in the study. A decreased 72h revisit rate could also be observed if a greater proportion of patients die at home, shortly after ED discharge.

Methodological considerations:

As 72h revisits only captures macro level patterns, future studies should include more granular endpoints (such as mortality) in the patients discharged from the ED, as well as more detailed data about which procedures and interventions were performed in the ED. As in patients with abdominal pain, this would allow for further clarification of whether the observed effect reflects an increased risk-taking

in ED staff at times of access block or not. Moreover, enrolling patients from several hospitals in the region would increase the statistical power to a level that allows for more thorough subgroup analysis as well as a higher external validity of the results. Apart from the above discussion about study endpoints and external validity, there were some power issues in Part IV requiring the categories of exposure to be collapsed to a dichotomy when comparing crude proportions of inpatient admission, and to three and two levels, respectively, when addressing revisits and revisits resulting in admission. This may have caused some information to be lost and is likely to explain part of the absence of an association between access block and hospital admission in the crude analysis.

Part V

The findings in Part V suggested that the permeability of the ED front-end slightly increased at times of access block, causing more patients to be admitted to the ED than otherwise. Results most likely reflected situations where primary triage nurses were tasked with assisting ED staff at times of high ED workload. This view was supported by the attenuation of results after adjusting for ED input in the multivariate models (i.e. part of the increase in permeability observed in the crude analysis was explained by the effects on ED workload exerted by high ED input). This is reassuring, as it implies that the nurses desired to err on the safe side and therefore admitted patients to the ED when in doubt, rather than took risks by triaging them out of the ED without proper evaluation. The lack of a significant association between hospital bed occupancy and the fraction of 72h revisits suggested that the appropriateness of discharges from primary triage was not reduced at times of access block. This was in line with the main findings, which suggested that patients were not increasingly refused entry to the ED, when inpatient beds were scarce. One may ask whether it is reasonable to tie scarce ED resources to a facility caring for the healthiest patients in the ED, at times of high ED workload. Moreover, it may be a risky practice to triage patients out of the ED, since a thorough evaluation is often needed in order to rule out potentially time-sensitive conditions.

Methodological considerations:

Cases that bypassed primary triage when the facility was highly utilized could not be separated from cases directly admitted to the ED for other reasons, in our data sources. Therefore, the impact of long queues to primary triage could not be quantified. As was the case in Part IV, limitations to study power warranted the collapsing of occupancy-strata when analyzing 72h revisits. Only 72h revisits to the ED at the study site were identified in the analysis. The generalizability of

study findings may be limited in areas where legislation (e.g., US EMTALA) prohibits diversion from the ED.

Conclusions

The major conclusions reached in each part of the thesis were as follows:

In Part I, findings suggested that ED patients were less likely to be admitted to the hospital at times of access block. The results remained when isolating the effects from the effects of potential confounders and other factors. The presence of a significant interaction term indicated that the effect was different for patients presenting with different main complaints. This was expected, as different main complaints signify underlying conditions of different severity.

Part II revealed no signs of an increased rate of inappropriate discharges from the ED at times of access block compared to otherwise, as measured by the 72h revisit rate.

Part III revealed that ED patients presenting with acute abdominal pain were also less likely to be admitted to a hospital bed, at times of access block than otherwise. This was in analogy with the findings in Part I. Patients discharged from the ED during access block were not more likely to revisit the ED within 72 hours than patients discharged otherwise and spent more time in the ED.

The findings in Part IV suggested that ED patients who presented with chest pain were less likely to be admitted to a hospital bed when access block prevailed, just as was the case for the undifferentiated ED population and for patients with abdominal pain. Patients discharged from the ED during access block were less likely to make an unplanned 72h revisit than patients discharged otherwise. Similarly to what was found in Part III, access block was associated to an increased EDLOS in patients discharged from the ED.

Part V revealed a slight decrease in the proportion of patients that were triaged out of the ED (i.e. refused admission to the ED) by the primary triage facility, at times of access block compared to otherwise. Most likely, the results reflected alternative uses of staff at times of high ED workload.

In an attempt to synthesize the conclusions reported above, Parts I-IV indicated the presence of an admission-bias by which patients were less likely to be admitted to the hospital when it was full. No increased inappropriateness of ED discharges was indicated by the 72h revisit rate, but since this outcome failed to take rare but fatal outcomes such as mortality into account, little can be said about the safety aspects of the effect. Consequently, future studies should examine the impact of access block on a wider range of outcomes, as well as on the use of ED resources

(e.g. lab tests and radiology), in order to allow for cost-effectiveness analyses that more directly address the viability of managing patients in the ED as an alternative to inpatient care. Such analyses should be executed before aggravating access block through reducing the number of inpatient beds further. The presence of local reimbursement systems that tie economic incentives to EDLOS may stimulate “unnecessary” admissions to hospital when inpatient beds are abundant, thereby maintaining bed crises and driving resource expenditure. This perspective should also be taken into account when intervening with access block and bed crises in the future.

Direction

Admitting an ED patient to an inpatient bed is frequently cited as the most expensive intervention an ED physician can make. This together with the increased demand for ED services calls for a clear definition of who should be admitted to an inpatient bed in the future. The study findings showed that hospital admissions were averted when inpatient beds were unavailable, but it is not clear whether the effect should be attributed to an increased proportion of patients that were safely treated and released from the ED or to increased risk taking among ED staff.

Reducing the number of “unnecessary” hospital admissions from the ED could relieve the stress on congested wards and limit monetary waste. However, proper cost-effectiveness analyses need to be conducted in order to formally evaluate the management of patients in the ED as an alternative to inpatient care. To my knowledge, few such studies exist, but downsizing hospital bed capacity remains a common means to handle budget constraints in Sweden and elsewhere.

Some additional strategies may prove effective in reducing inappropriate inpatient admissions from the ED. Most of them are generic, while others may be more applicable to healthcare systems similar to that in Sweden:

- Improve access to and continuity in primary care. Efforts in this area should not be limited to certain areas of society, as well-established links between socioeconomic class and health suggest that disadvantaged groups do not require less health supervision than other people do. An additional advantage of maintaining continuity in primary care is that primary care physicians may be able to apply a more holistic perspective than is possible in subspecialized healthcare settings.
- Promote cooperation and information exchange between primary care establishments, EDs, and inpatient clinics. One example would be “frequent flyer” projects that target patients who heavily utilize ED

resources. In a recent review article, the risks experienced by this group of patients were quantified as frequent hospital admissions and increased mortality (296). Such collaborations may also provide a suitable platform for the development of solutions for secure information exchange between providers, patients, and other stakeholders.

- Invest in outpatient alternatives to inpatient care. The positive effects of home-care initiatives and clinical service organizations have been reported in several contexts. Obvious targets of these initiatives are patients with chronic diseases that tend to exacerbate, (e.g., those with heart failure or COPD).
- Develop algorithms and protocols for when residents in nursing homes and community care facilities should be referred to the ED. Such protocols have been evaluated in prospective trials of patients with pneumonia and COPD. Referring elderly patients to the ED most often results in hospital admission, with associated waits, stress and costs, even though the patients could often be safely managed in the nursing home.
- Increase and formalize the use of palliative turning points. Many patients experience unnecessary stress and interference only because no sufficient strategy for their end-of-life care has been agreed upon. This action would also be in line with the demands for patient participation expressed in the newly enacted Swedish Patient Act.
- Monitor performance in emergency care. When developing quality indicators, the amount of value that an activity adds tends to be more important to the patient than its duration. Even though an array of quality indicators exists, bluntly reporting them monthly or bimonthly may reveal little about the resilience of an organization. By taking the system utilization level (e.g., in-hospital bed occupancy or ED bed occupancy) into account while interpreting quality indicators, such information can be captured. Due to the binary nature of many quality indicators, logistic regression may prove valuable. Even though their description is outside the scope of this thesis, several methods for process-monitoring are available, examples of which include statistical process control (SPC) (297) and the Balanced Scorecard (298, 299). Moreover, outpatient mortality in patients discharged from the ED should be systematically measured, in order to address the safety of ED discharges.
- Define the tasks that the ED should be primarily occupied with. The delimitation between EDs and inpatient care often varies between hospitals, more often because of tradition than as a result of thorough cost-effectiveness analysis and solid evidence. Clear boundaries are important in order for the ED to establish its role as an independent hospital department. EDs could be equipped to perform some of the tasks

traditionally taken on by inpatient wards. One type of inpatient care that may be accomplished quicker and cheaper in an ED observation unit is the observation and evaluation of suspected ACS of low risk. Developing protocols for implementation and follow-up in collaboration with inpatient clinics may present the additional advantage of opportunities to found constructive relationships between the leadership of the ED and the inpatient clinics. It has been suggested that 5-10% of ED volume is expected to be managed in the EDOU and that a ratio of five patients per nurse is appropriate (131)

- Improve processes in inpatient clinics in order to reduce waste. A common problem today is that deficiencies in downstream capacity cause patients to needlessly spend time waiting in inpatient beds while other patients board in the ED.
- Invest in primary prevention in the form of public education. This would be in line with the increased patient participation that is demanded in the new Swedish Patient Act. Risk groups are obvious targets of this action, but educating the youngest citizens may also prove beneficial from the perspective of long-term compliance.
- Tie reimbursement systems to patient health outcomes. This should not be confused with tying reimbursement systems to surveys of patient satisfaction, since these often struggle with low response rates and, as a result, tend to be biased.
- Frontload competence in the ED by employing physicians specialized in emergency medicine. By being used to a wider spectrum of differential diagnoses, EM physicians may improve efficiency in ED operations and limit unnecessary referrals. Additionally, forbidding unsupervised work by the most junior physicians in Swedish EDs will remove the incentive to admit ED patients to hospital beds just in order to make them see a specialist physician.
- Discontinue the use of the 4-hour target. By tying reimbursements to EDLOS, many Swedish county councils have introduced incentives for unnecessary hospital admissions, thereby maintaining bed crises and driving economic waste.
- Legislate against the delayed discharges imposed on hospital wards by the municipalities, which frequently refuse to accept treated patients from the hospital before five business-days have passed.

Populärvetenskaplig sammanfattning

Bakgrund:

Patientflödet genom en akutmottagning regleras framförallt av tre typer av faktorer. Dessa rör i tur och ordning inflödet-, genomflödet- och utflödet av patienter. Faktorer som reglerar inflödet rör efterfrågan på sjukvård (t.ex. samhällsdemografi och tillgång på primärvård), medan faktorer som reglerar genomflödet till största delen rör akutmottagningens interna processer (t.ex. sådana för diagnostik och behandling). Faktorer som reglerar utflödet från akutmottagningen innefattar tillgången på vårdplatser inom slutenvården och tillgången på uppföljande vård. Forskarsamhället är i princip enigt i att utflödet av patienter från akutmottagningen har särskilt stor inverkan på det fenomen som kallas trängselproblematik. Trängselproblematik kan definieras som en situation där stor efterfrågan på akutmottagningens resurser leder till att vårdbehovet hos en eller flera patienter inte kan tillgodoses. Bland faktorerna som reglerar utflödet från akutmottagningen intar tillgången på slutenvårdsplatser en särställning. Mycket akademisk nit har riktats mot det fenomen som i internationella sammanhang kallas ”boarding” och som innebär att patienter som ska läggas in på sjukhuset tvingas vänta kvar på akutmottagningen eftersom vårdplatser saknas. De väntande patienterna knyter upp resurser, som gör det svårare för akutmottagningen att möta behoven hos övriga patienter. Mindre väl studerat är huruvida brist på slutenvårdsplatser leder till att endast de sjukaste patienterna läggs in på sjukhus och att övriga i större utsträckning färdigbehandlas på akutmottagningen.

Avhandlingens övergripande syfte var att undersöka huruvida prioriteringen av vårdnivå bland akutmottagningens patienter påverkas av brist på slutenvårdsplatser (d.v.s. om färre patienter läggs in när sjukhuset är fullt). Det sista delarbetet fokuserade på huruvida fler patienter nekades att komma in på akutmottagningen när det råder vårdplatsbrist på sjukhuset, av den instans som kallas primärtriage och vars syfte är att sortera ut och hänvisa de patienter som upplevs för friska för att vara på akutmottagningen till annan vårdnivå (exempelvis till primärvården).

Metod:

Studien genomfördes på ett datamaterial hämtat från akutmottagningen vid Helsingborgs lasarett, under åren 2011-2013. Avhandlingens första del omfattade 118,668 akutbesök och fokuserade på huruvida vårdplatsbrist påverkade beslutet om att lägga in patienter från akutmottagningen på sjukhuset. Statistiska modeller konstruerades för att ta hänsyn till effekter av kända störfaktorer. Avhandlingens

andra del fokuserade på huruvida vårdplatsbrist ledde till att patienter felaktigt skickades hem från akutmottagningen. Syftet var att utvärdera hypotesen om att brist på slutenvårdsplatser får personalen på akutmottagningen att ta risker i form av att skicka hem patienter som egentligen är för sjuka, och att kvaliteten på den vård som ges de patienter som färdigbehandlas på akutmottagningen således skulle vara sämre än den de annars skulle fått på sjukhuset. Hypotesen utvärderades med hjälp av effektmåttet oplanerade återbesök inom 72 timmar, som Socialstyrelsen upphöjt till nationell indikator år 2013. Avhandlingsdel tre och fyra fokuserade på samma utkomster som avhandlingsdel ett och två, men för patienter som sökte för de två vanligaste sökorsakerna på akutmottagningen: buksmärta respektive bröstsmärta. Avhandlingens femte och sista del fokuserade på prioriteringen av vårdnivå vid ankomsten till akutmottagningen. I avhandlingsdelen mättes associationen mellan tillgång på slutenvårdsplatser och sannolikheten för att en patient skulle triageras ut från akutmottagningen (exempelvis till primärvården) av den instans som kallas primärtriage.

Resultat:

Avhandlingens första del visade att patienter som sökte akutmottagningen då sjukhuset var fullt lades in i mindre utsträckning än patienter som sökte akutmottagningen annars. Detta även efter justering för flera störfaktorer (oddskvot 0.67–0.81 vid beläggningsgrad >105% jämfört med <95%). Avhandlingsdelar tre och fyra visade att effekten kvarstod även för de patienter som sökte för buksmärta respektive bröstsmärta. Avhandlingens andra del visade att de patienter som skickades hem från akutmottagningen då sjukhuset var fullt inte återsökte i större utsträckning än de som skickades hem annars. Avhandlingsdel tre visade att detsamma gällde för patienter som sökte med buksmärta. Patienter med bröstsmärta som skickades hem då sjukhuset var fullt återsökte dock i mindre utsträckning än de som skickades hem annars. I avhandlingens femte del sågs ingen ökad andel hänvisningar från primärtriage till annan vårdnivå då sjukhuset var fullt.

Diskussion/slutsats:

Fynden visar att vårdplatsbrist inom slutenvården var associerad med att färre patienter lades in på sjukhuset. Detta gällde såväl för en osorterad patientpopulation som för patienter med buk- respektive bröstsmärta. Avsaknaden av en ökad andel oplanerade återbesök till akutmottagningen kan tolkas som att strategin inte medförde ökade medicinska risker, men eftersom indikatorn inte fångar alla aspekter av sjukdom bör framtida studier tillägnas beskrivningen av mer specifika utkomster för enskilda patientgrupper. En viktig sådan är dödlighet efter att ha blivit hemskickad från akutmottagningen. Framtida studier bör ta hänsyn till sådana utkomster tillsammans med förändringar i akutmottagningens resursutnyttjande, för att bättre kunna utvärdera vård på akutmottagningen som ett alternativ till vård på sjukhuset.

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Paper I

ORIGINAL RESEARCH

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The probability of patients being admitted from the emergency department is negatively correlated to in-hospital bed occupancy – a registry study

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Abstract

Background: The association between emergency department (ED) overcrowding and poor patient outcomes is well described, with recent work suggesting that the phenomenon causes delays in time-sensitive interventions, such as resuscitation. Even though most researchers agree on the fact that admitted patients boarding in the ED is a major contributing factor to ED overcrowding, little work explicitly addresses whether in-hospital occupancy is associated to the probability of patients being admitted from the ED. The objective of the present study is to investigate whether such an association exists.

Methods: Retrospective analysis of data on all ED visits to Helsingborg General Hospital in southern Sweden between January 1, 2011, and December 31, 2012, was undertaken. The fraction of admitted patients was calculated separately for strata of in-hospital occupancy <95%, 95–100%, 100–105%, and >105%. Multivariate models were constructed in an attempt to take confounding factors, e.g., presenting complaints, age, referral status, triage priority, and sex into account. Subgroup analysis was performed for each specialty unit within the ED.

Results: Overall, 118,668 visits were included. The total admitted fraction was 30.9%. For levels of in-hospital occupancy <95%, 95–100%, 100–105%, and >105% the admitted fractions were 31.5%, 30.9%, 29.9%, and 28.7%, respectively. After taking confounding factors into account, the odds ratio for admission were 0.88 (CI 0.84–0.93, $P > 0.001$) for occupancy level 95–100%, 0.82 (CI 0.78–0.87, $P > 0.001$) for occupancy level 100–105%, and 0.74 (CI 0.67–0.81, $P > 0.001$) for occupancy level >105%, relative to the odds ratio for admission at occupancy level <95%. A similar pattern was observed upon subgroup analysis.

Conclusions: In-hospital occupancy was significantly associated with a decreased odds ratio for admission in the study population. One interpretation is that patients who would benefit from inpatient care instead received suboptimal care in outpatient settings at times of high in-hospital occupancy. A second interpretation is that physicians admit patients who could be managed safely in the outpatient setting, in times of good in-hospital bed availability. Physicians thereby expose patients to healthcare-associated infections and other hazards, in addition to consuming resources better needed by others.

Keywords: Bed occupancy; Emergency care; Patient admission

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Background

The association between emergency department (ED) overcrowding and poor patient outcomes is well described [1-7]. Recent work suggests that ED overcrowding compromises timeliness of resuscitative care, with potentially devastating effects to individual patients [8], and that ED overcrowding might have increased in magnitude over time [9]. Strategies to reduce overcrowding have been proposed [2,10-15] but their extent of implementation is variable [4,14,16].

Boarding of admitted patients in the ED has been highlighted several times as the major cause of ED overcrowding [1,2,14,17-19]. Boarding is, in turn, caused by scarcity of inpatient beds [1,2,14,16,17]. Some consider ED overcrowding a symptom of the broader dysfunction in the healthcare system, rather than a problem residing solely in the ED [20-22]. Although not thoroughly investigated, full capacity protocols and other solutions aiming at distributing workload throughout the hospital instead of accumulating patients in the ED appear promising [16,23]. When asked, patients prefer boarding in inpatient hallways to ED hallways [24]. Other specific solutions to reduce boarding include synchronizing discharges from inpatient wards with admission peaks [25] and to eliminate bottlenecks delaying discharge, e.g., availability of surgery [26].

Admission is a comparably expensive intervention for ED patients, the use of which needs to be scrutinized in order to better understand cost-effectiveness in the evolving role of the EDs in Sweden and worldwide [21]. There is some evidence for physicians avoiding hospital admissions as an adaptive strategy in crowded conditions [21,27], but few studies have explicitly addressed the correlation between in-hospital occupancy and the probability of admission. Beds are often scarce in Swedish hospitals, inciting the Swedish National Board of Health and Welfare to make the matter subject to national follow-up since 2012.

The objective of the present study is to test whether the probability of being admitted from the ED is correlated to the in-hospital occupancy at the time of patient presentation in the ED. The study is primarily hypothesis-generating and constitutes part of an extensive project designed to elucidate the effects of high in-hospital occupancy on the treatment of acutely ill patients in the country council region of Skåne in southern Sweden.

Methods

Study design

This registry study included all visits to the ED of Helsingborg General Hospital registered in the ED information system Patientliggaren[®] between 1st January 2011 and 31st December 2012, not resulting in referral to

another hospital. No further selection was made, in order not to introduce selection bias.

Setting

Helsingborg General Hospital is one of four emergency hospitals in the region of Skåne in southern Sweden. It is a 420-bed hospital with an ED serving a population of around 250,000. Due to tourism, the population expands to nearly 300,000 during the summer. The annual ED census is around 60,000, with approximately 15% of patients arriving by ambulance. Patients are registered in the information system Patientliggaren[®] by a secretary upon arrival. Patients who arrive by ambulance or are referred by a physician gain access to the ED after registration. Non-referred patients are given access to the ED after registration in accordance with pre-defined guidelines or are further evaluated by a nurse in primary triage. Such cases could be referred elsewhere (e.g., to primary care). About 10–15% of all visits enter the ED via primary triage. After entering the ED, secondary triage is performed by a nurse. The 4-level triage system “medical emergency triage and treatment system” was used during the study period. It addresses the medical urgency of a case by evaluating the main complaint and vital parameters. The triage priority number is registered in Patientliggaren[®] directly after secondary triage. Only physicians may down-prioritize patients.

Patients are directed to separate units for Surgery, Orthopaedics, Medicine, and Otolaryngology in a triage-to-specialty model after secondary triage. A complementary unit staffed by emergency physicians capable of handling all complaints except for psychiatric, otolaryngologic, ophthalmologic, and paediatric (medicine) was also introduced in 2010 and operates from 8 am to 11 pm daily. There are separate EDs for children with medical conditions (<18 years of age) and for patients with obstetric/gynaecologic, psychiatric or ophthalmologic complaints. These are not included in the study. Patients with suspected hip-fractures and some geriatric patients with high acuity conditions are admitted directly and bypass the ED. Hand surgery, neurosurgery, and thoracic surgery is not available at the hospital. The availability of endovascular surgery and percutaneous coronary intervention is limited afterhours (between 17.00–08.00) and during weekends. Patients with these needs are referred to Skane University Hospital in Lund. Swedish national reimbursement systems are tied to a goal of 80% of visits with ED length of stay ≤4 hours. ED length of stay at Helsingborg hospital is shorter than in academic EDs overseas [4,28]. Access to emergency care in Sweden is not dependent on private insurance status.

Data sources

Data on referral status was retrieved from the in-hospital information system PASiS. Data on all other variables was

Table 1 Descriptive data

	All units	Medicine unit	Surgery unit	Orthopaedics unit	Emergency physician unit	Otolaryngology unit
Admission status	Not admitted	18,493 (52.8%)	18,608 (67.2%)	23,484 (85.1%)	11,580 (69.2%)	9,886 (85.2%)
	Admitted	36,617 (30.9%)	9,102 (32.8%)	4,116 (14.9%)	5,160 (30.8%)	1,716 (14.8%)
Age (yrs)	0-17	16,381 (13.8%)	4,846 (17.5%)	6,231 (22.6%)	1,747 (10.4%)	3,508 (30.2%)
	18-39	30,097 (25.4%)	7,684 (27.7%)	7,442 (27.0%)	4,087 (24.4%)	3,019 (26.0%)
	40-64	33,468 (28.2%)	7,328 (26.4%)	7,372 (26.7%)	4,855 (29.0%)	2,774 (23.9%)
	>65	38,722 (32.6%)	7,852 (28.3%)	6,555 (23.8%)	6,051 (36.1%)	2,301 (19.8%)
Referral status	Not referred	91,168 (76.8%)	22,187 (80.1%)	21,461 (77.8%)	12,698 (75.9%)	7,617 (65.7%)
	Referred	18,667 (15.7%)	3,379 (12.2%)	4,265 (15.5%)	3,156 (18.9%)	2,815 (24.3%)
	Missing	8,833 (7.4%)	2,144 (7.7%)	1,874 (6.8%)	886 (5.3%)	1,170 (10.1%)
Triage priority	1	5,689 (4.8%)	1,437 (5.2%)	277 (1.0%)	587 (3.5%)	90 (0.8%)
	2	18,461 (15.6%)	3,898 (14.1%)	2,181 (7.9%)	2,626 (15.7%)	620 (5.3%)
	3	63,828 (53.8%)	16,730 (60.4%)	15,522 (56.2%)	9,670 (57.8%)	4,483 (38.6%)
	4	28,502 (24.0%)	5,245 (18.9%)	8,703 (31.5%)	3,598 (21.5%)	6,182 (53.3%)
	Missing	2,188 (1.8%)	400 (1.4%)	917 (3.3%)	259 (1.5%)	227 (2.0%)
Sex	Female	58,567 (49.4%)	13,169 (47.5%)	13,232 (47.9%)	8,512 (50.8%)	5,498 (47.4%)
	Male	60,101 (50.6%)	14,541 (52.5%)	14,368 (52.1%)	8,228 (49.2%)	6,104 (52.6%)
In-hospital occupancy	<95%	53,405 (45.0%)	13,129 (47.4%)	12,880 (46.7%)	6,391 (38.2%)	4,739 (40.8%)
	95-100%	34,258 (28.9%)	8,070 (29.1%)	7,930 (28.7%)	4,558 (27.2%)	3,248 (28.0%)
	100-105%	23,920 (20.2%)	5,167 (18.6%)	5,251 (19.0%)	4,296 (25.7%)	2,637 (22.7%)
	>105%	7,085 (6.0%)	1,344 (4.9%)	1,539 (5.6%)	1,495 (8.9%)	978 (8.4%)
LWBS	Yes	2,332 (2.0%)	706 (2.5%)	571 (2.1%)	216 (1.3%)	147 (1.3%)
	Yes	18,616 (15.7%)	4,198 (15.1%)	5,778 (20.9%)	2,678 (16.0%)	1,859 (16.0%)
Total visits		118,668	27,710	27,600	16,740	11,602

Fractions rounded off to nearest decimal place.

retrieved from the ED information system Patientliggaren®. Matching was performed by the hospital informatics unit using QlikView® software. Data on in-hospital bed occupancy was retrieved from the informatics unit and was matched by the author (MB) using IBM® SPSS® Statistics 19. Data in Patientliggaren® has been validated by the regional epidemiological unit "EpiCentrum" of the region of Skåne, as part of another project, in 2012–2013.

Statistical analysis

The admitted fraction was computed for strata of in-hospital occupancy of <95%, 95–100%, 100–105%, and >105%. Subgroup analysis was performed for each specialty unit.

Binary logistic regression models were developed in an attempt to take confounding factors into account. Clinical judgement governed the decision of which predictors to screen for inclusion, but was inevitably tainted by data availability. Decisions were made *a priori* to analysis. Screened variables were the 10 most common presenting complaints, age-group, referral status, triage priority, presentation on a shift experiencing many visits (see definition below), presentation on night shift and during weekends, sex, leaving without being seen (LWBS), entering ED via primary triage, time to physician and in-hospital occupancy.

Age was grouped into intervals 0–18 years, 18–40 years, 40–64 years, and ≥65 years; youths in Sweden become of age at 18 and pension-age is 65 years. The youngest two age categories were merged in the analysis of the medicine unit, as children with medical conditions are assessed in a separate ED. In-hospital occupancy was categorized as <95%, 95–100%, 100–105%, and >105%. Presentation on a shift experiencing many visits was constructed as a dichotomous variable indicating presentation on one of the 25% of shifts subject to most visits (adjusted for shift type and unit). The night shift was set from 00.00 am to

08.00 am. Reference intervals for categorical predictors were in-hospital occupancy <95%, triage priority 3, age ≥65 years, presenting complaint other than the 10 most common, and not being referred to the ED. Since causes of missing data were not known, imputation was not considered an option and missing data was instead indicated by a separate category in each model [29].

Predictors were tested for crude association with the outcome before entering the preliminary primary effects model. Associations weaker than $P = 0.25$, but of clinical importance, were still included [30]. Multicollinearity testing was performed using Spearman correlation [31]. Selection of interaction terms screened for inclusion in the final models was governed by clinical significance and terms were added to models one by one rather than stepwise [30]. Model fit was evaluated through Nagelkerke's R^2 . The association between each predictor and the outcome were addressed by the -2LL and the Wald statistics. Models were screened for influential cases by addressing standardized residuals and Cook's distance.

Data was anonymized before entering SPSS. Ethical approval was granted by the ethics committee of Lund in February 6, dnr 2013/11.

Results

Between January 1, 2011 and December 31, 2012, 120,203 visits to the medicine, surgery, orthopaedics, emergency medicine, and otolaryngology units were registered in Patientliggaren®; 118,668 visits did not result in referral to another hospital and were included in the study. Of these, 35,016 were directed to the medicine unit, 27,710 to the surgery unit, 27,600 to the orthopaedics unit, 16,740 to the emergency physician unit, and 11,602 to the otolaryngology unit. The admitted fraction was 30.9% overall, 47.2% for the medicine unit, 32.8% for the surgery unit, 14.9% for the orthopaedics unit, 30.8% for the emergency

Table 2 Admitted fraction at different levels of in-hospital occupancy

		<95%	95–100%	100–105%	>105%	Total
All units	Admitted	16,845 (31.5%)	10,580 (30.9%)	7,159 (29.9%)	2,033 (28.7%)	36,617 (30.9%)
	Total	53,405	34,258	23,920	7,085	118,668
Medicine unit	Admitted	7,826 (48.1%)	4,831 (46.2%)	3,065 (46.7%)	801 (46.3%)	16,523 (47.2%)
	Total	16,266	10,452	6,569	1,729	35,016
Surgery unit	Admitted	4,358 (33.2%)	2,554 (31.6%)	1,718 (33.2%)	472 (35.1%)	9,102 (32.8%)
	Total	13,129	8,070	5,167	1,344	27,710
Orthopaedics unit	Admitted	1,959 (15.2%)	1,247 (15.7%)	694 (13.2%)	216 (14.0%)	4,116 (14.9%)
	Total	12,880	7,930	5,251	1,539	27,600
Emergency physician unit	Admitted	1,932 (30.2%)	1,424 (31.2%)	1,376 (32.0%)	428 (28.6%)	5,160 (30.8%)
	Total	6,391	4,558	4,296	1,495	16,740
Otolaryngology	Admitted	770 (16.2%)	524 (16.1%)	306 (11.6%)	116 (11.9%)	1,716 (14.8%)
	Total	4,739	3,248	2,637	978	11,602

physician unit, and 14.8% for the otolaryngology unit. Detailed descriptive data are reproduced in Table 1.

Unadjusted analysis showed that the admitted fraction was smaller in strata of increasing in-hospital occupancy. For levels of in-hospital occupancy <95%, 95–100%, 100–105%, and >105% the admitted fractions were 31.5%, 30.9%, 29.9%, and 28.7%, respectively. The same pattern was observed in most of the subgroup analyses. Detailed results from the unadjusted analysis are reproduced in Table 2.

All predictors screened for inclusion in the multivariate models were included because of clinical significance, except from time to physician, which was omitted due to violation of the assumption of linearity in the logit [31].

Table 3 shows the association between in-hospital occupancy level and probability for admission, with confounding factors from presenting complaint, age group, referral status, triage priority, presentation on a shift experiencing many visits, presentation on night shift/weekend, sex, LWBS, and entering the ED via primary triage taken into account.

A clear association between increasing in-hospital occupancy and decreased odds ratio for admission was seen overall, with the odds ratios of admission being 0.88 (CI 0.84–0.93, $P < 0.001$) for occupancy level 95–100%, 0.82 (CI 0.78–0.87, $P < 0.001$) for occupancy level 100–105%, and 0.74 (CI 0.67–0.81, $P < 0.001$) for occupancy level >105%, relative to the odds ratio for admission

Table 3 Odds ratios for admission, with confounding factors taken into account

	Occupancy level	B	SE	Wald	Sig. (P)	OR (CI)
All units	<95% (ref)					1.00
	95–100%	-0.12	0.025	24.26	<0.001	0.88 (0.84–0.93)
	100–105%	-0.20	0.029	47.17	<0.001	0.82 (0.78–0.87)
	>105%	-0.31	0.046	43.96	<0.001	0.74 (0.67–0.81)
Nagelkerke R2	0.370					
Medicine unit	<95% (ref)					1.00
	95–100%	-0.14	0.030	22.60	<0.001	0.87 (0.82–0.92)
	100–105%	-0.22	0.036	36.46	<0.001	0.80 (0.75–0.86)
	>105%	-0.33	0.060	29.86	<0.001	0.72 (0.64–0.81)
Nagelkerke R2	0.367					
Surgery unit	<95% (ref)					1.00
	95–100%	-0.16	0.035	20.35	<0.001	0.85 (0.80–0.91)
	100–105%	-0.17	0.042	17.11	<0.001	0.84 (0.78–0.91)
	>105%	-0.17	0.070	6.10	0.014	0.84 (0.73–0.97)
Nagelkerke R2	0.261					
Orthopaedics unit	<95% (ref)					1.00
	95–100%	0.004	0.049	0.006	0.940	1.00 (0.91–1.11)
	100–105%	-0.26	0.061	18.62	<0.001	0.77 (0.68–0.87)
	>105%	-0.24	0.096	6.41	0.011	0.78 (0.65–0.95)
Nagelkerke R2	0.421					
Emergency physician unit	<95% (ref)					1.00
	95–100%	-0.006	0.049	0.016	0.899	0.99 (0.90–1.10)
	100–105%	-0.033	0.051	0.41	0.520	0.97 (0.88–1.07)
	>105%	-0.25	0.075	10.60	0.001	0.78 (0.68–0.91)
Nagelkerke R2	0.357					
Otolaryngology unit	<95% (ref)					1.00
	95–100%	0.002	0.12	0.000	0.989	1.00 (0.79–1.28)
	100–105%	-0.36	0.15	5.99	0.014	0.70 (0.53–0.93)
	>105%	-0.40	0.22	3.44	0.063	0.67 (0.44–1.02)
Nagelkerke R2	0.287					

Results from binary logistic regression models taking into account confounding from presenting complaint, age-group, referral status, triage priority, presentation on a shift experiencing many visits, presentation on night shift and during weekend, sex, leaving without being seen and entering ED via primary triage.

at occupancy level <95%. A similar pattern was observed upon subgroup analysis. Table 3 shows the coefficients of overall fit.

Discussion

Both crude analysis and the adjusted analysis revealed a negative association between in-hospital occupancy and the odds ratio of patient admission. With few exceptions, the same pattern was observed upon subgroup analysis. The association between in-hospital occupancy level and decreased probability for admission established in the present study is supported by the findings of physicians aiming at reducing admissions when in-hospital beds are scarce [21,27].

Taking confounding from several factors into account, the multivariate models generated much information on factors associated with high probability of admission, which was omitted from this paper in order not to overshadow the main results. Most of the observed patterns were expected, i.e., increasing triage priority and age being associated with higher odds ratios of admission and different main complaints exhibiting different odds ratios for admission.

Limitations

Despite its place on the study design hierarchy, the authors believe that this retrospective descriptive study was good at approximating reality as it included a large population with a wide range of complaints of varying severity, being treated by typical personnel. No bias is introduced through selection, which might be the case in controlled studies [32]. Considering the prevailing savings requirements at Helsingborg General Hospital, a rapid and inexpensive approach was also considered most ethical. The external validity of the results has to be met with a sound measure of scepticism, as the study was performed in a single hospital. Future studies should address this subject by comparing results between the different hospitals in the region.

Goodness-of-fit statistics indicate a limited ability of the multivariate models to predict admissions, suggesting that variables not included play a role. Previous studies indicate that co-morbidity is an important factor [33] and the authors believe that vital parameters would be desirable to include in future models. It would also be interesting to include effects of queuing for radiology or laboratory resources. However, the size and completeness of the data material should eliminate some of the bias from these factors and the authors wish to point out that the study objective was to reveal any correlation between in-hospital occupancy and the probability for admission, not to develop a tool for predicting admissions. For this purpose, the chosen method is adequate [34]. Age was divided into fairly few intervals in order to

minimize risk for incomplete information from the variables. Given the large number of cases, this approach was too cautious and possibly concealed interesting findings in the population ≥ 65 years old.

Conclusions

High in-hospital occupancy is associated with decreased odds ratios for admission of patients presenting in the ED of Helsingborg General Hospital during the study period. One interpretation is that a fraction of patients who would benefit from inpatient care instead received suboptimal care in outpatient settings at times of high in-hospital occupancy. The authors propose that downstream effects of such a relationship would be measurable, e.g., by increased incidence of unplanned revisits to the ED.

A second interpretation is that physicians admit patients who could be managed safely in the outpatient setting, in times of good in-hospital bed availability. Physicians thereby expose patients to healthcare-associated infections and other hazards, in addition to consuming resources better needed by others. A study addressing the first of these hypotheses is already initiated.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

MB, KI and ML all participated in developing the study protocol. MB carried out gathering and matching of data and also carried out the statistical analyses. MB carried out the writing of the draft. All authors carried out proofreading of repeated versions of the manuscript.

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Paper II

ORIGINAL RESEARCH

Open Access

Associations between in-hospital bed occupancy and unplanned 72-h revisits to the emergency department: a register study

Mathias C Blom^{1*}, Fredrik Jonsson², Mona Landin-Olsson¹ and Kjell Ivarsson¹

Abstract

Background: A possible downstream effect of high in-hospital bed occupancy is that patients in the emergency department (ED) who would benefit from in-hospital care are denied admission. The present study aimed at evaluating this hypothesis through investigating associations between in-hospital bed occupancy at the time of presentation in the ED and the probability for unplanned 72-hour (72-h) revisits to the ED among patients discharged at index. A second outcome was unplanned 72-h revisits resulting in admission.

Methods: All visits to the ED of a 420-bed emergency hospital in southern Sweden between 1 January 2011 and 31 December 2012, which did not result in admission, death, or transfer to another hospital were included. Revisiting fractions were computed for in-hospital occupancy intervals <85%, 85% to 90%, 90% to 95%, 95% to 100%, 100% to 105%, and ≥105%. Multivariate models were constructed in an attempt to take confounding factors from, e.g., presenting complaints, age, referral status, and triage priority into account.

Results: Included in the study are 81,878 visits. The fraction of unplanned 72-h revisits/unplanned 72-h revisits resulting in admission was 5.8%/1.4% overall, 6.2%/1.4% for occupancy <85%, 6.4%/1.5% for occupancy 85% to 90%, 5.8%/1.4% for occupancy 90% to 95%, 6.0%/1.6% for occupancy 95% to 100%, 5.4%/1.6% for occupancy 100% to 105%, and 4.9%/1.4% for occupancy ≥105%.

In the multivariate models, a trend to lower probability of unplanned 72-h revisits was observed at occupancy ≥105% compared to occupancy <95% (OR 0.88, CI 0.76 to 1.01). No significant associations between in-hospital occupancy at index and the probability of making unplanned 72-h revisits resulting in admission were observed.

Conclusions: The lack of associations between in-hospital occupancy and unplanned 72-h revisits does not support the hypothesis that ED patients are inappropriately discharged when in-hospital beds are scarce. The results are reassuring as they indicate that physicians are able to make good decisions, also while resources are constrained.

Keywords: Emergency medicine; Emergency medicine/organization and administration; Emergency medicine/statistics and numerical data; Bed occupancy

Background

High in-hospital bed occupancy has been associated with prolonged wait in the emergency department (ED) [1,2], spread of hospital-associated infections [3,4], and declining mental health among personnel [5]. Simulation studies suggest that periods of demand exceeding bed capacity are more frequent in systems with high-average occupancy

[6,7]. Pooling of resources appears to enable larger systems to operate at higher average levels of bed occupancy [8]. Application of the principles of queuing theory to hospital systems has shown that variability in admission rate or in length of stay (LOS) in hospital wards is associated with the presence and length of queues for in-hospital beds [8,9].

Capacity planning in many hospital systems relies on average occupancy and average LOS, which makes them susceptible to overflow when these variables vary [8]. Several studies highlight the advantages of minimizing

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variability in elective volumes, to minimize overflows and increase efficiency [10-13].

Additional simulation studies have shown that performing discharges earlier in the day prevents collision of peak occupancy and peak demand for admissions, which results in lower daily peak and average bed occupancy [14-16].

A recent study undertaken by the authors revealed an association between high in-hospital bed occupancy and decreased probability of admission from the ED [17]. A possible downstream effect is that patients who benefit from in-hospital care are denied admission and instead receive care in the outpatient setting. The objective of the present study was to evaluate this hypothesis through investigating associations between in-hospital bed occupancy at the time of presentation in the ED and the probability of unplanned 72-h revisits to the ED, among patients discharged at their index visit.

Methods

Study design

The study was conducted as a retrospective register study, including all visits to the ED of a 420-bed emergency hospital in southern Sweden between 1 January 2011 and 31 December 2012, not resulting in admission, death, or transfer to another hospital. In order to avoid selection bias, no further selection was made.

Setting

The ED of Helsingborg Hospital serves a population of around 250,000. Due to tourism, the population expands to nearly 300,000 during summer. It is one of the four emergency hospitals in the region of Skåne in southern Sweden. The annual ED census is around 60,000, with approximately 15% of patients arriving by ambulance. Patients are registered in the information system Patientliggaren® by a secretary upon arrival. Patients who arrive by ambulance or are referred by a physician gain access to the ED directly after registration. Other patients gain access to the ED in accordance with predefined guidelines, or are further evaluated by a nurse in primary triage. Patients could be referred elsewhere from primary triage (e.g., to primary care). Patients who gain access to the ED undergo secondary triage, which is performed by a nurse. The following is controlled upon secondary triage: Airway, respiratory rate, and SpO₂ (pulse oximetry), heart rate, and blood pressure (non-invasive), alertness (Reaction Level Scale (RLS)), and body temperature. The four-level triage system 'Medical emergency triage and treatment system' (METTS) was used for secondary triage during the study period. The triage priority is registered in Patientliggaren® directly after the secondary triage. Only physicians may down-prioritize patients (Table 1).

Patients are directed to separate units for Surgery, Orthopedics, Medicine, and Otolaryngology in a triage-to-specialty model after the secondary triage. A complementary unit staffed by emergency physicians capable of handling various complaints except for psychiatric, otolaryngologic, ophthalmologic, and pediatric (medicine) complaints was introduced in 2010 and operates from 8 am to 11 pm daily. There are separate EDs for children with medical conditions (<18 years of age) and for patients with obstetric/gynecologic, psychiatric, or ophthalmologic complaints. Visits to these EDs were not included in the study. Patients with suspected hip fractures or ST elevation myocardial infarction diagnosed in the ambulance bypass the ED in fast tracks and were not included either. Hand surgery, neurosurgery, and thoracic surgery are not available in the hospital. The availability of endovascular surgery and percutaneous coronary intervention is limited from 5 pm to 08 am. Patients with such needs are referred to Skåne University Hospital and were not included in the study.

Physical ED records for patients who are advised to revisit the ED are stored at each specialty desk. Nurses indicate whether a visit is a planned revisit in Patientliggaren® upon patient arrival. Swedish national reimbursement systems are tied to a goal of 80% of visits with ED LOS ≤4 h. At in-hospital bed occupancy close to 100%, the hospital utilizes full-capacity protocols.

Data sources

Data was retrieved from the ED information system Patientliggaren® and the in-hospital information system PASIS®. Data matching was performed by the hospital Informatics Unit using QlikView® software.

Statistics

Occupancy was defined as the overall proportion of occupied beds in the hospital at whole-hour intervals. All patients registered in Patientliggaren® during an interval were assigned the same occupancy.

The proportion of visits resulting in an unplanned 72-h revisit was computed for in-hospital occupancy levels of <85%, 85% to 90%, 90% to 95%, 95% to 100%, 100% to 105%, and ≥105%. Subgroup analysis was performed for each specialty unit. Computations were repeated for unplanned 72-h revisits resulting in admission.

Adjusted analysis was performed in an attempt to take confounding factors into account, using binary logistic regression models. Perceived clinical significance governed the decision of screened predictors but was inevitably tainted by data availability. Screened variables were the following: specialty unit, presenting complaint at index, referral status at index, triage priority at index, age group, sex, index presentation on an intense shift, index presentation on a night shift and during weekends,

Table 1 Overview of the four category triage system METTS

Clinical parameter	Triage category			
	1 (red)	2 (orange)	3 (yellow)	4 (green)
	Airway obstruction			
	Stridor			
Oxygen saturation	SpO ₂ < 90% with oxygen supply	SpO ₂ < 90% without oxygen supply	SpO ₂ 90% to 95% without oxygen supply	SpO ₂ > 95% without oxygen supply
Respiratory rate (breaths/min)	>30 or <8	>25		8 to 25
Pulse (beats/min)	Regular >130 or irregular >150	>120 or <40	>110 or <50	50 to 110
Systolic bp (mmHg)	<90			
Consciousness	Unconscious	RLS 2 to 3/somnolence	Disoriented	Alert
	Seizures	Temperature >41°C or <35°C	Temperature >38.5°C	Temperature 35°C to 38.5°C

METTS was used during the study period. The most urgent category from which the patient scores is selected.

leaving without being seen (LWBS) at index, entering ED via primary triage at index, time to physician at index, and in-hospital occupancy at index. The variable indicating presentation on an intense shift was constructed as a dichotomous variable indicating presentation on one of the 25% of shifts subject to most visits (adjusted for shift type and unit). Night shift was set from 12:00 mn to 08:00 am. Presenting complaint was constructed as a nominal variable indicating the ten most common complaints, using the remainder as reference.

The medicine unit was used as reference among the specialty units. Age was grouped into intervals 0 to 18 years, 18 to 40 years, 40 to 65 years, and ≥65 years. Age ≥65 years was used for reference. Youths in Sweden become of age at 18 and pension age is 65 years.

For the multivariate models, in-hospital occupancy was categorized as <85%, 85% to 90%, 90% to 95%, 95% to 100%, 100% to 105%, and ≥105%. The reference interval was set to <85%. Sensitivity analysis was performed using occupancy <95% as reference.

Predictors were tested for crude association with the outcome before entering the preliminary primary effects model. Associations weaker than $P = 0.25$, but of clinical importance were still included [18]. Multicollinearity testing was performed using Spearman correlation [19].

Selection of interaction terms screened for inclusion in the final models was governed by perceived clinical significance and made *a priori* to analysis. Variables were manually added to the models, rather than stepwise [18]. Missing data was indicated by a separate category and included in the models [20].

Model fit was evaluated through Nagelkerke's R^2 . The association between each predictor and the outcome was addressed by the -2LL and the Wald statistics. The final models were the models with the highest explanatory value and the fewest number of predictors [19]. Additionally, the models were screened for influential cases by addressing standardized residuals and Cook's distance.

Statistical analyses were performed in IBM® SPSS® Statistics 19. Data was anonymized before analysis. The Regional Ethical Review Board in Lund granted ethical approval for the study.

Results

A total of 83,586 ED visits resulting in discharge were registered in Patientliggaren®. Of these, 81,878 did not result in referral to another hospital or death and were hence included in the study.

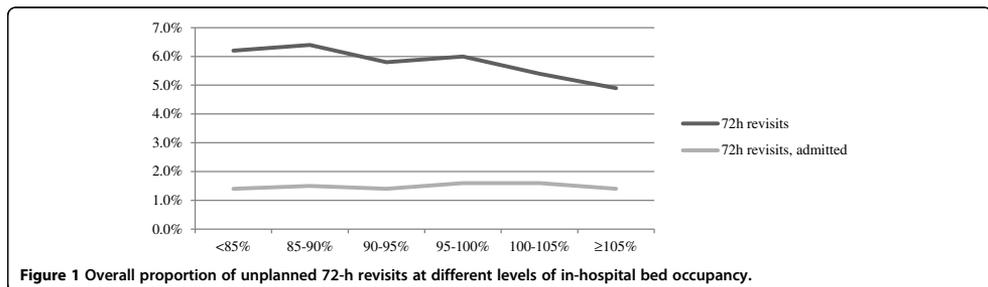
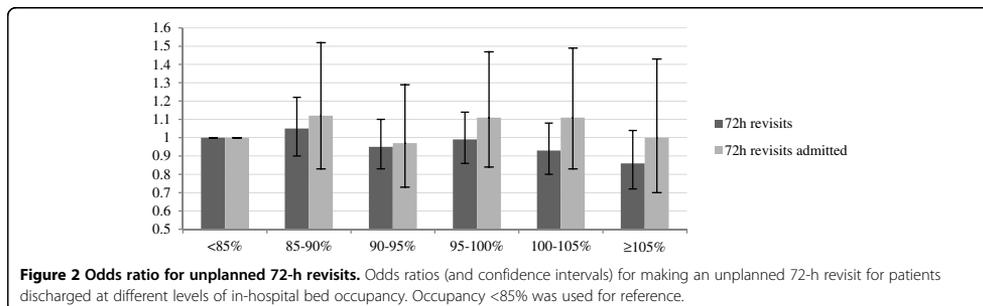


Figure 1 Overall proportion of unplanned 72-h revisits at different levels of in-hospital bed occupancy.



Unadjusted analysis

Out of the 81,878 cases, 4,753 cases resulted in an unplanned 72-h revisit, and 1,213 cases resulted in an unplanned 72-h revisit and admission. Proportions of unplanned 72-h revisits/unplanned 72-h revisits resulting in admission were 5.8%/1.5% overall, 6.2%/1.4% for occupancy <85%, 6.4%/1.5% for occupancy 85% to 90%, 5.8%/1.4% for occupancy 90% to 95%, 6.0%/1.6% for occupancy 95% to 100%, 5.4%/1.6% for occupancy 100% to 105%, and 4.9%/1.4% for occupancy ≥105% (Figure 1).

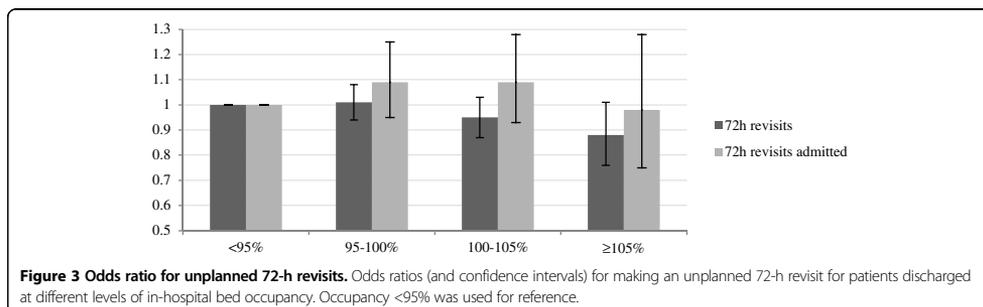
Adjusted analysis

All predictors screened for inclusion in the multivariate models were included, except from time to physician, which was omitted as it violated the assumption of linearity in the logit [19]. No significant associations between in-hospital bed occupancy at the index visit and the probability for unplanned 72-h revisits was observed in the model using occupancy <85% as the reference. In the sensitivity analysis, a trend to lower odds for unplanned 72-h revisits was observed among patients being discharged from the ED at occupancy ≥105% relative to at <95%, OR 0.88 (CI 0.76 to 1.01, *P* = 0.062). No significant associations between in-hospital bed occupancy and the probability for unplanned 72-h revisits resulting in admission were seen in either model. A full account of

the models (including coefficients of overall fit) is shown in Additional file 1 (Figures 2 and 3).

Discussion

No significant association between making an index visit to the ED at times of high in-hospital bed occupancy and the probability for making an unplanned 72-h revisit was revealed in the multivariate model using occupancy <85% for reference. In the sensitivity analysis, a trend to lower odds for revisiting was observed among patients being discharged at occupancy ≥105% relative to at <95%. As the hospital rarely operates at occupancy <85%, the sensitivity analysis is considered most stable. The results are supported by the unadjusted analysis, which reveals that 4.9% of cases who were discharged at in-hospital occupancy ≥105% made an unplanned 72-h revisit, compared to 6.2% at occupancy <85%. The overall fraction of unplanned 72-h revisits of 5.8% is higher than the 1.4% to 5.5% described in other studies [21-25]. No associations between in-hospital bed occupancy and the probability of making an unplanned 72-h revisit resulting in admission were observed, either in the adjusted or unadjusted analyses. The 1.5% of discharged cases who made an unplanned revisit resulting in admission is somewhat higher than the 1.1% to 1.2% reported in other studies [22,23].



One interpretation of the results is that the patients who are discharged from the ED at times of high in-hospital bed occupancy are not sicker than the patients being discharged at other times. Considering our previous results, which showed that the probability for being admitted from the ED is lower at times of high in-hospital occupancy [17], the present results suggest that ED physicians make good decisions, also when resources are constrained.

Limitations

The Nagelkerke R^2 coefficients (given in Additional file 1) indicate that the variables that were not available for study, e.g., diagnosis and co-morbidity, influenced the outcome in the adjusted analyses. This is also supported by the presence of some influential cases. The relatively large sample size is thought to have balanced some of this effect. As diagnosis and IPLOS vary across specialties, it might have been better to model occupancy in different in-hospital units separately. Unfortunately, this was not possible. The external validity of the results is limited, as the study was performed in a single hospital. The fact that some groups of patients are cared for in separate EDs (children with medical conditions and patients with obstetric/gynecologic, psychiatric, or ophthalmologic complaints) and others bypass the ED in fast tracks (patients with STEMI diagnosed in the ambulance and patients with suspected hip fractures) is important to note when comparing results to other EDs. Another limitation is that patients making an unplanned revisit to another ED in the region are not included in the study, but empirical knowledge suggests that this fraction is small. The authors also recognize that the chosen outcomes are not designed to evaluate the appropriateness of ED discharges. Their selection was motivated by frequent use in other studies and that the Swedish National Board for Health and Welfare made unplanned 72-h revisits subject to national follow-up from April 2013.

Conclusions

The present study yields no support for the hypothesis that ED patients who are discharged from the ED at times of high in-hospital bed occupancy make more unplanned 72-h revisits to the ED than patients who are discharged when bed availability is better. The results are reassuring as they indicate that ED physicians make good decisions, also while resources are constrained. As the present study includes only two endpoints, the reader should interpret it carefully. The implementation of information systems capable of measuring more outcomes on the individual level and tracking patients on their journey across medical specialties is an essential step to allow more accurate description of potential risks.

Additional file

Additional file 1: A full account of the models (including coefficients of overall fit). Table S2: fraction of unplanned 72-h revisits (rev) for different levels of in-hospital occupancy. **Table S3:** data from adjusted analysis, with in-hospital bed occupancy <85% used for reference. **Table S4:** data from adjusted analysis, with in-hospital bed occupancy <95% used for reference.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

MB, FJ, KI, and MLO designed the study protocol together. MB gathered and matched the data and carried out the statistical analyses and the writing of the draft. All authors proofread repeated versions of the manuscript. All authors read and approved the final manuscript.

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Paper III

**Patients presenting at the emergency department with acute abdominal pain
are less likely to be admitted to inpatient wards during hospital crowding: a
registry study**

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ABSTRACT

Background

Also known as hospital crowding, shortage of inpatient beds is a common cause of emergency department (ED) boarding and overcrowding, which are both associated with impaired quality of care. Recent studies have suggested that hospital crowding not simply causes boarding in EDs, but may also result in that patients are less likely to be admitted to the hospital from the ED. The present study's aim was thus to investigate whether this effect remained for patients with acute abdominal pain, for which different management strategies are available. Access block was defined in terms of hospital occupancy and the appropriateness of ED discharges addressed as 72h revisits to the ED.

Methods

As a registry study of ED administrative data, the study examined a population of patients who presented with acute abdominal pain at the ED of a 420-bed hospital in southern Sweden during 2011–2013. Associations between exposure and outcomes were addressed in contingency tables and by logistic regression models.

Results

Crude analysis revealed a negative association between access block and the probability of inpatient admission (38.6% admitted at 0–95% occupancy, 37.8% at 95–100% occupancy, and 35.0% at $\geq 100\%$ occupancy) ($p < .001$). No significant associations between exposure and 72h revisits emerged. Multivariate models indicated an odds ratio of inpatient admission of 0.92 (95% CI: 0.86–0.98) at 105% occupancy compared to at 95% occupancy.

Conclusions

Study findings support the hypothesis that patients with acute abdominal pain are less likely to be admitted to the hospital from the ED at times of access block. No association with 72h revisits was seen, but future studies need to address more granular outcomes in order to clarify the safety aspects of the practice.

Keywords [MeSH]: Emergency medicine, emergency medicine organization and administration, acute abdominal pain, bed occupancy

INTRODUCTION

Shortage of inpatient beds—that is, access block or “hospital crowding”—is a prominent cause of emergency department (ED) boarding [1,2] and overcrowding [1–7]. Both effects are associated with impaired quality of care [2], the latter often for causing treatment delays [9–11], increased mortality [11–13], and patient dissatisfaction [14,15]. Recent studies have suggested that hospital crowding not only causes boarding in the ED, but also that ED patients are less likely to be admitted to the hospital at times of access block and instead are discharged home [16]. Such admission-bias may reflect a strategy by which ED staff averts inpatient admission in all but the sickest patients [16, 17]. Patients with acute abdominal pain frequently seek care in the ED and different management strategies are available [18]. One strategy is to admit them to the hospital for early laparoscopy (EL), which helps establishing a definitive diagnosis [19–22], but associated risks make its net benefits questionable [19,20,23,24]. Another strategy is close observation in the inpatient setting, often accompanied by radiology [18–20]. Some argue that observation is comparable to EL [25]. Both these strategies involve admission to the inpatient setting. Radiology may improve diagnostic accuracy and be used for ruling out time-sensitive conditions [26–30]. Radiology is generally available in EDs and low-dose protocols are under development [31]. Due to the different management strategies available, we hypothesize that patients presenting at the ED with abdominal pain are affected by the previously described admission-bias, at times of access block.

The aim of the present study was thus to evaluate this hypothesis, by investigating whether ED patients with acute abdominal pain are less likely to be admitted to

the hospital at times of access block. The appropriateness of ED discharges was addressed by the 72h revisit rate.

METHOD

Study design

For this registry study of ED administrative data, the sample consisted of patients who presented with a primary complaint of abdominal pain at the surgical and emergency medicine (EM) specialty units in the ED of a 420-bed hospital in southern Sweden during 2011–2013. Presentations at these facilities were selected in order to exclude other causes of abdominal pain, such as those assessed at the internal medicine specialty unit. Patients less than 18 years of age, who died in the ED, who left the ED against medical advice, and/or who were transferred to another hospital were also excluded.

Setting

The ED of Helsingborg General Hospital serves a population of roughly 250,000, which expands to more than 300,000 in the summer. It is one of four emergency hospitals in the region of Skåne in southern Sweden. The annual ED census of physician visits shows an increase from just below 60,000 to 65,000 from 2011 to 2013. Upon arrival, all patients were registered by secretaries in the information system Patientliggaren[®]. The approximately 15% of patients who arrived by ambulance, or who have been referred to the ED by a physician—typically from primary care—gained access to the ED directly after registration. Other patients gained access to the ED in accordance with predefined guidelines or were further evaluated by a nurse in primary triage. Patients can be referred elsewhere from

primary triage (e.g., to primary care) and thereby denied admission to the ED. Patients who gain access to the ED received secondary triage performed by a nurse using a five-level triage system implemented in 2013 and known as the rapid emergency triage and treatment system (RETTS[®]) [32], though during its validation period was called the medical emergency triage and treatment system (METTS) [33]. Of the five levels of RETTS[®], one signifies no indication for emergency care, which was often assigned to patients referred to another level of care by primary triage. Patient triage category was registered in Patientliggaren[®] by the nurse who performed secondary triage.

After secondary triage, patients were directed to separate units for surgery, orthopedics, medicine, and otolaryngology in a triage-to-specialty model [34]. A complementary unit staffed by emergency physicians capable of addressing various complaints except for psychiatric, otolaryngologic, ophthalmologic, and pediatric (medicine) ones was introduced in 2010 that operated from 8 am to 11 pm daily. In late 2012, this facility assumed increased responsibility for surgical patients. There are separate EDs for children with medical conditions (<18 years of age) and for patients with obstetric/gynecologic, psychiatric, or ophthalmologic complaints. Visits to these EDs were excluded in this study, as were patients less than 18 years of age assessed at the surgical or EM facility. Patients transferred from the surgical/EM facilities to another facility who did not return—most were transferred to the obstetric/gynecologic facility and there received final assessment—were also excluded, though patients who received their final assessment at the surgical/EM facilities after transferring from another facility were included. In the case of a scheduled revisit to the ED, physical ED records

from the index visit were stored at each specialty desk, and triage nurses made notes in Patientliggaren[®] upon patient arrival. Radiology and laboratory analyses were available to ED patients around the clock. Since the clinical observation unit was introduced in late 2012, patients admitted there have been considered admitted to the hospital for billing purposes and are treated as such in the present study.

Sample size

After exclusion criteria were applied, the study material was not subject to additional restrictions in order to prevent bias. *Post hoc* power calculations were performed to determine cutoff levels for strata of in-hospital bed occupancy to use in crude comparisons for $\alpha = 0.05$ and 80% power ($1-\beta = 0.80$) [35]. Differences of 3% for inpatient admission, 2% for 72h revisits, and 1% for 72h revisits resulting in admission were specified as clinically relevant *a priori* to analysis. Ten events per predictor were considered adequate for multivariate analysis [36].

Data sources

Data regarding patient visits were retrieved from the ED information system Patientliggaren[®]. Data concerning hourly occupancy levels were obtained from the hospital informatics unit and extracted by a professional data manager. The datasets were merged by an author (MB) in the programming language Python[™].

Variables

Access block was defined in terms of hospital occupancy (the number of occupied beds in the hospital divided by the number of staffed beds) at the beginning of the

hour when the patient presented at the ED. The total occupancy for somatic wards accepting patients from the ED (i.e., not surgical wards only) was used because of the full-capacity protocols that took effect during hospital crowding, thereby causing patients admitted from the ED to be distributed evenly among wards sorting under different departments. Sample size calculations revealed that the study material was sufficient for applying a three-category variable (<95%, 95–100%, ≥100%) for access block to evaluate differences in the proportion of inpatient admissions across, in the crude analysis, though only a dichotomous variable was acceptable for evaluating 72h revisits and ED length of stay (EDLOS). The cutoff for the dichotomous variable was specified as 100% occupancy before sample size calculation. Occupancy of 100% was preferred to that of 95%, since the latter is less than the median occupancy of the hospital and therefore may not reflect access block at the study site. Inpatient admission is indicated in Patientliggaren[®] as a dichotomous variable. Unplanned 72h revisits were defined as revisits within 72 hours of the initial visit, to the study site or to the nearby ED of Ängelholm General Hospital, and that were not marked as planned revisits in Patientliggaren[®]. Sex, triage category, and high ED input were all coded as dichotomous variables. The triage dichotomy reflects medical urgency (i.e., priority 1 and 2 patients were considered time sensitive as they needed to be seen by a physician within 15 min). High ED input was indicated by the 75th percentile of shifts receiving most ED visits (adjusted for time of week). Time of year (Dec–Feb and Jun–Aug versus the rest), time of week (Mon and Sat–Sun versus the rest), and shift (00:00–08:00, 08:00–16:00, and 16:00–00:00) were constructed as three-level categorical variables.

Crude analysis

Fisher's exact test was applied to compare crude proportions of outcomes at different levels of occupancy. The Mann–Whitney U test was used to compare EDLOS across strata of in-hospital bed occupancy for patients not admitted to an inpatient ward during their index visit. Due to the recent controversy regarding applying non-parametric tests to non-normal data in large datasets [37], their parametric counterparts were used for comparison.

Multivariate analysis

Logistic regression was used to adjust for any confounders and covariates in multivariate analyses of the association of access block with inpatient admission and 72h revisits. Directed acyclic graphs were used to identify the appropriate set of independent variables for adjustment [38,39]. Causal models were developed by all authors using the free online tool DAGitty (Appendices 1 and 2) [40]. The minimally sufficient adjustment set for addressing all three outcomes consisted of time of year, time of week, and shift (time of day). The adjustment set was entered into the logistic equation using the entry method instead of a stepwise method. Interaction terms included were based on empirical knowledge and comprised occupancy*shift. Independent variables of the minimally sufficient adjustment set not significantly associated with the outcome were retained to prevent bias [38,39]. Interaction terms of weaker association with the outcome than $p = .05$ upon inclusion in the model were omitted.

The adequacy of expected cell counts was assessed in contingency tables [41], while multicollinearity was addressed by variance inflation factor (VIF) and

tolerance statistics. Age and in-hospital bed occupancy were screened for linearity in the logit using the Box–Tidwell approach [41] and, if violated, were transformed to the ordinal scale. Multivariate outliers were addressed by Mahalanobis distance and evaluated according to an χ^2 distribution at $p = .001$ [42]. To improve the face validity of the multivariate models, sensitivity analysis was performed by expanding the minimally sufficient adjustment set (step 1) in two subsequent steps. In step 2, triage category, age, and sex were added to the list of covariates. In step 3, three variables—the first indicating whether the patient entered the ED via primary triage, the second indicating whether ED input was high during the simultaneous shift, and the third indicating year 2013, which captures the introduction of RETTS[®], increased responsibility for surgical patients at the EM facility, and the introduction of an observation unit—were added to the list of covariates. The selection of variables for expansion was based on knowledge of risk factors for admission in the present dataset [16] and the possibility of a wider spectrum of underlying disease in females suffering from abdominal pain.

Sensitivity analyses for 72h revisits excluded triage priority, whether the patient entered the ED via primary triage, and whether the patient presented during a shift with high input. The model's goodness-of-fit was evaluated with the likelihood ratio test, and effect size was evaluated with Nagelkerke's R^2 . The likelihood ratio and Wald tests were used to evaluate the contribution of individual variables, and model dispersion parameters were used to rescale the Wald statistic appropriately [42]. Standardized residuals were used to identify influential cases. Since a total of three multivariate models and two crude comparisons were developed for each

outcome, Bonferroni adjustment was applied to yield significance at $p = .01$. Statistical analyses were performed in the Statistical Package for the Social Sciences[®] version 22 (IBM). The Regional Ethical Review Board in Lund granted ethical approval for the study (dnr 2013/11).

RESULTS

Participants

In all, 52,970 visits were made to the EM and surgical facilities of the ED at Helsingborg General Hospital during 2011–2013. Of these visits, 23,884 cases presented with a primary complaint of abdominal pain, 3,778 of which were less than 18 years of age and thus excluded, along with three patients who died in the ED, 421 who left against medical advice, and 62 who were transferred to another hospital. The final study population was thus 19,620 cases.

Missing data

Missing data appeared only in the variable indicating triage category ($83/19,620 = 0.4\%$). Since no verified predictors of triage priority were present in the dataset, regression imputation was not feasible, which in conjunction with its scant number warranted the exclusion of cases from multivariate analyses [42].

	Outcome		
	Inpatient admission	72h revisit	72h revisit, admitted
Triage priority 1	216 (73.7%)	9 (12%)	3 (4%)
Triage priority 2	1,771 (62.2%)	133 (12.3%)	62 (5.8%)
Triage priority 3	4,928 (34.7%)	847 (9.1%)	309 (3.3%)
Triage priority 4	419 (19.1%)	115 (6.5%)	33 (1.9%)
Missing priority	14 (16.9%)	5 (7%)	2 (3%)
Age 18–40 years	1,881 (25.5%)	484 (8.8%)	158 (2.9%)
Age 40–65 years	2,392 (35.5%)	399 (9.2%)	144 (3.3%)
Age 65–80 years	1,909 (51.0%)	174 (9.5%)	74 (4.0%)
Age >80 years	1,166 (66.3%)	52 (8.8%)	33 (5.6%)
Male	3,206 (40.6%)	522 (11.1%)	214 (4.6%)
Female	4,142 (35.4%)	587 (7.8%)	195 (2.6%)
Dec–Feb	1,832 (37.9%)	253 (8.4%)	106 (3.5%)
Sep–Nov, Mar–May	3,687 (37.6%)	554 (9.0%)	212 (3.5%)
Jun–Aug	1,829 (36.8%)	302 (9.6%)	91 (2.9%)
Mon	1,277 (38.5%)	179 (8.8%)	62 (3.0%)
Tue–Fri	4,283 (37.4%)	643 (9.0%)	238 (3.3%)
Sat–Sun	1,788 (36.8%)	287 (9.4%)	109 (3.6%)
00:00 – 08:00	1,347 (36.7%)	253 (10.9%)	97 (4.2%)
08:00 – 16:00	3,280 (36.8%)	426 (7.6%)	162 (2.9%)
16:00 – 00:00	2,721 (38.7%)	430 (10.0%)	150 (3.5%)
≥100% occupancy	1,577 (35.0%)	245 (8.3%)	99 (3.4%)
95–100% occupancy	2,161 (37.7%)	N/A	N/A
0–95% occupancy	3,610 (38.5%)	N/A	N/A
<100% occupancy	N/A	864 (9.3%)	310 (3.3%)
Total	7,348 (37.5%)	1,109 (9.0%)	409 (3.3%)

Table 1. Descriptive data of the study population across study outcomes

7,348/19,620=37.5% of cases were admitted to hospital. Crude analyses revealed that the admitted proportion was smaller at times of more pronounced access block: 35.0% at ≥100% occupancy, 37.7% at 95–100% occupancy, and 38.5% at <95% occupancy ($p < .001$). 1,109 (9.0%) of the 12,272 cases discharged revisited within 72 hours. 409 (3.3%) revisited and were admitted. No significant associations were established between access block and 72h revisits. EDLOS was more than 20 min longer (3.76 vs. 3.38 hours) ($p = .01$) at ≥100% in-hospital occupancy than at <100% for patients of triage priority 1–2, while no difference

was detected for patients of triage priority 3–4 ($p=.23$) or the total group ($p=.61$) (Table 2). Parametric and non-parametric tests agreed on this point.

	Triage priority				Total ($p=.61$)	
	1–2 ($p=.01$)		3–4 ($p=.23$)		<100% ($N = 9,337$)	$\geq 100\%$ ($N = 2,935$)
	<100% ($N = 887$)	$\geq 100\%$ ($N = 267$)	<100% ($N = 8,392$)	$\geq 100\%$ ($N = 2,657$)		
Occupancy						
EDLOS [h] (IQR)	3.38 (2.33–4.85)	3.76 (2.40–5.67)	3.17 (2.17–4.52)	3.08 (2.08–4.59)	3.17 (2.18–4.55)	3.13 (2.10–4.70)

Table 2. Median emergency department length of stay (EDLOS) in relation to occupancy, stratified by triage priority (69 cases missing)

Adjusted results

Age violated the assumption of linearity in the logit and was transformed to the ordinal scale (18–40, 40–65, 65–80, and >80 years) before inclusion in the multivariate models. Cutoffs were established prior to analysis and relied on perceived clinical relevance. The range of 40–65 years was used as a reference. Hospital occupancy passed the test for linearity and was included in its continuous form in all the multivariate models. Cell counts were below five for <85% and >105% occupancy levels, suggesting that the interval in between allowed for the most reliable models. Since Mahalanobi’s distance, tolerance, and VIF statistics did not indicate any major problems with multicollinearity or multivariate outliers, all models were pursued as planned.

Outcome	Adj. set	Reg. coeff	SE	Wald chi ²	p	OR	95% CI for OR	
							Lower	Upper
Admission	Step 1	-0.008	0.003	8.612	.003	0.992	0.986	0.997
	Step 2	-0.008	0.003	6.401	.011	0.992	0.985	0.998
	Step 3	-0.008	0.003	6.394	.011	0.992	0.986	0.998
72h revisit	Step 1	0.005	0.006	0.714	.398	1.005	0.993	1.017
	Step 2	0.005	0.005	0.683	.409	1.005	0.994	1.015
	Step 3	0.005	0.005	0.906	.341	1.005	0.995	1.016
72h revisit, admitted	Step 1	0.003	0.009	0.099	.753	1.003	0.985	1.022
	Step 2	0.002	0.008	0.105	.745	1.002	0.988	1.018
	Step 3	0.003	0.007	0.180	.671	1.003	0.989	1.017

Table 3. Odds ratio (OR) for outcome per percent change in in-hospital bed occupancy, logistic regression, adjustment sets 1-3

The negative association between access block and the likelihood of inpatient admission was significant in all three models. Table 3 presents an account of the change in odds for admission resulting from a 1% increase in hospital bed occupancy. The models addressing admission did not suffer from large residuals and predicted a fair portion of events. Meanwhile, models relating access block to 72h revisits, both resulting in subsequent admission and not, revealed no significant associations (Table 3). These models exhibited some large residuals and had lower explanatory value, indicating that variables not available to us influenced the outcome. The odds ratios (ORs) for hospital admission at 5% increments relative to 95% occupancy are displayed in figure 1.

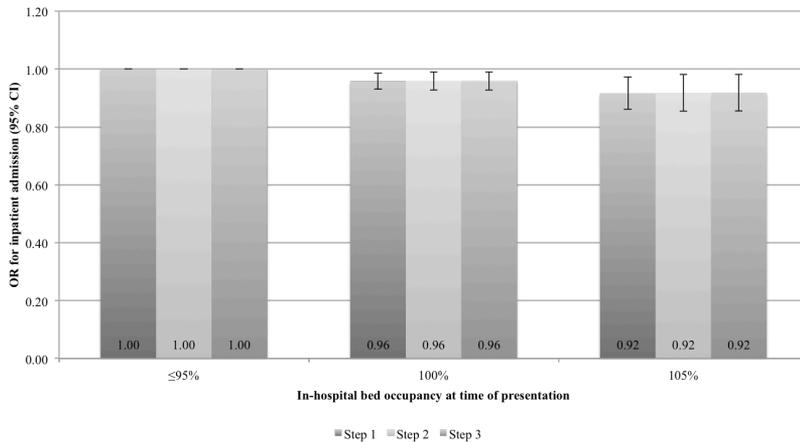


Figure 1. Odds-ratio of inpatient admission with 95% in-hospital bed occupancy used for reference, adjustment sets 1-3

DISCUSSION

The negative association between access block and the probability of inpatient admission supports the hypothesis that patients with acute abdominal pain are less likely to be admitted to the hospital at times of access block. The effect appears somewhat attenuated compared to in an undifferentiated ED population [16]. The sample size and power calculations indicate that the study was powered well to detect the pre-specified differences. The absence of an association to 72h revisits suggests that discharges from the ED were no more inappropriate at times of access block than otherwise. However, this outcome does only capture macro level patterns and says nothing about rare (but potentially disastrous) outcomes such as mortality. The positive association between in-hospital bed occupancy and EDLOS in patients of triage priority 1–2 who were ultimately discharged from the ED could be interpreted as support for the hypothesis of their being subject to more evaluation and/or treatment in the ED at times of access block. However, it could also be indicative of longer waiting times for diagnostics and treatment in

the ED. Given that some of the underlying conditions in the patient population are time-sensitive, this could be of detriment to patients. Future studies should include more granular endpoints (such as mortality) in the patients discharged from the ED, as well as more detailed data about which procedures and interventions were performed in the ED, in order to clarify the safety aspects of the observed effect. Such studies would allow for answering the question about whether the observed admission-bias is an expression of increased risk taking in ED staff (by discharging potentially sick patients home) or if a larger proportion of patients receive necessary evaluation and treatment in the ED and that unnecessary inpatient admissions thereby are averted, at times of access block. Future studies should also include more hospitals in order to improve the external validity of the results and increase statistical power to a level that allows for more thorough subgroup analysis.

Conclusion

This study supports the hypothesis that patients with acute abdominal pain are less likely to be admitted to the hospital at times of access block. There was no association between access block and 72h revisits to the ED, but more granular outcome measures need to be addressed in future studies in order to clarify the safety aspects of the observed effect.

AUTHOR CONTRIBUTIONS

MB participated in writing the study protocol, merging the datasets, developing causal models, conducting statistical analyses, and drafting the manuscript. ML, MLO, FJ, and KI participated in developing both the study protocol and causal models, as well as in commenting on the manuscript.

AUTHOR INFORMATION

MB is a doctoral candidate in emergency medicine at Lund University and a resident physician in internal medicine at Norrbottens Läns Landsting.

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CONFLICTS OF INTEREST

KI was the head of the division responsible for the emergency department where the study was conducted. FJ is currently the chair of that emergency department. All other authors declare that they have no conflicts of interest with the study.

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Paper IV

Patients who present at the emergency department with chest pain are less likely to be admitted to a hospital bed at times of access block - a registry study

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ABSTRACT

Background

Recent studies suggest that lack of inpatient beds (“access block”) is not only associated with ED overcrowding, but also with a decreased likelihood of being admitted to a hospital bed, for ED patients. The aim of the present study is to assess whether this effect is present also in patients presenting at the ED with chest pain.

Methods

The study was conducted as a registry study on ED admin data from a 420-bed hospital in southern Sweden, 2011-2013. Access block was defined in terms of hospital occupancy. The association between the exposure and the outcome was addressed in contingency tables and by logistic regression models.

Results

Multivariate models revealed that patients presenting at the ED at times of access block were less likely to be admitted to the hospital, with OR 0.87 (95% CI 0.79–0.95) at 105% hospital occupancy compared to at 95%. Likewise, patients discharged from the ED at times of access block were less likely to revisit the ED within 72h.

Conclusions

The study results suggest that patients who present at the ED with chest pain are less likely to be admitted to a hospital bed, at times of access block. ED discharges were no more inappropriate at times of access block than discharges made otherwise, as measured by the 72h revisit rate, but more granular outcomes

(such as mortality) need to be addressed in future studies in order to clarify the safety aspects of the effect.

Keywords [MeSH]: Emergency Medicine, Emergency Medicine – organization & administration, chest pain, bed occupancy

INTRODUCTION

Emergency Department (ED) overcrowding is associated with impaired quality of care [1-2] and one of its most frequently cited causes is access block or “hospital crowding,” which impairs ED output [1-5]. Recent studies suggest that access block is also associated with ED patients being less likely to be admitted to a hospital bed [6,7]. The effect may reflect decisions made in order to circumvent inpatient care by performing necessary evaluation and treatment in the ED, but the safety aspects are not clear. Patients with chest pain are common in the ED and often require admission to hospital. Despite clinical decision rules [8-9] and increasingly sensitive biomarkers [10-12], time-sensitive conditions such as myocardial infarction (MI), may be hard to rule out without inpatient observation [13-15]. The aim of the present study is to address whether patients presenting at the ED with chest pain are less likely to be admitted to a hospital bed, at times of access block than otherwise. The appropriateness of ED discharges is addressed by the 72h revisit rate.

METHOD

Study design

The study was conducted as a registry study on ED admin data. Study subjects were patients presenting at the internal medicine and emergency medicine (EM) facilities in the ED of a 420-bed hospital in southern Sweden between 2011 and 2013, with a main complaint of non-traumatic chest pain. Cases under 18 years of age, who died in the ED, who left the ED against medical advice or were transferred to another hospital, were all excluded.

Setting

The ED of Helsingborg General Hospital serves a population of around 250,000, which expands to nearly 350,000 during summer. It is one of the four emergency hospitals in the region of Skåne in southern Sweden. The annual ED census is around 60,000, with approximately 15% of patients arriving by ambulance.

Patients are registered in the information system Patientliggaren[®] by a secretary upon arrival. Patients who arrive by ambulance or are referred by a physician gain access to the ED directly after registration. The remainder of patients gain access to the ED in accordance with predefined guidelines, or are further evaluated by a nurse in primary triage. Patients could be referred elsewhere from primary triage (e.g., to primary care) without seeing a physician in the ED. After entering the ED, patients undergo secondary triage with a five-level triage algorithm called 'Rapid emergency triage and treatment system' (RETTS[®]). The system was called 'Medical emergency triage and treatment system' (METTS) during the validation period in 2011-2012. One of the five levels indicates that there is no need for emergency care and is frequently assigned to patients who are referred to another level of care by primary triage. Therefore, the system stratifies medical urgency into 4 categories for practical purposes. The most urgent category is to be assessed by a physician immediately, the second within 15 minutes, the third within one hour and the fourth within a non-specified timeframe. The triage category is registered in Patientliggaren[®] by the nurse who performs secondary triage.

Patients are directed to separate units for surgery, orthopedics, internal medicine, and otolaryngology in a triage-to-specialty model after secondary triage [16]. A complementary unit staffed by emergency physicians capable of handling various complaints, except for psychiatric, otolaryngologic, ophthalmologic, and pediatric

complaints, was introduced in 2010 and operates from 8 am to 11 pm daily. There are separate EDs for children with medical conditions (<18 years of age) and for patients with obstetric/gynecologic, psychiatric, or ophthalmologic complaints. Visits to these EDs were not included in the study. In case of a scheduled revisit to the ED, physical ED records from the index visit are stored at each specialty desk and the triage nurse makes a notation in Patientliggaren[®] upon patient arrival. ED physicians have access to laboratory analyses and radiology around the clock. Patients diagnosed with an ST-elevation MI (STEMI) in the ambulance are transferred directly to the PCI facility and do not pass through the ED. PCI is available at the study site during the day; at other times, patients are referred to Skåne University Hospital in Lund. An ECG is taken pre-hospital for patients with chest pain arriving in the ED by ambulance. Such patients are generally triggering an alarm, which makes resources available to them upon arrival. The standard troponin T assay was replaced by an Hs-Troponin T assay in 2013. A clinical observation unit was introduced in late 2012, but patients admitted to this unit are considered admitted to the hospital for billing purposes and appear as such in the present study.

Sample size

The study material was not subject to restrictions after applying the exclusion criteria, in order to limit bias. *Post hoc* power calculations were performed to determine the number of strata (see cut-offs in the “variables” section) of in-hospital bed occupancy to use for group comparisons in the crude analysis ($\alpha = 0.05$, $1-\beta = 0.80$) [17]. Differences of 3% for inpatient admission, 2% for 72h revisits and 1% for 72h revisits resulting in admission were specified as clinically

relevant prior to analysis. Sample sizes allowing for 10 events per predictor were considered appropriate for multivariate analysis [18].

Data sources

Data on patient visits was retrieved from the ED information system Patientliggaren[®]. Data on hourly occupancy levels was obtained from the hospital informatics unit. A professional data manager extracted the data. One of the authors (MB) merged the datasets in the programming-language Python[™].

Variables

Access block was defined in terms of hospital occupancy. The hospital occupancy rate was measured as the number of occupied beds in the hospital divided by the number of beds the hospital was staffed for, at the hour of patient presentation in the ED. Sample-size calculations revealed that the study material was sufficient for dividing occupancy into two categories ($<100\%$, $\geq 100\%$) when evaluating inpatient admissions, three categories ($<95\%$, $95-100\%$, $\geq 100\%$) when evaluating 72h revisits and four categories ($<95\%$, $95-100\%$, $100-105\%$ and $\geq 105\%$) when evaluating EDLOS. The study was slightly underpowered (77.6%) to evaluate differences in 72h revisits resulting in admission, also when using two categories. The cut-offs for occupancy strata were specified prior to analysis. In-hospital bed occupancy $<85\%$ has traditionally been used for the reference level when discussing target occupancy in hospitals, following Bagust et al [19]. However, since the median bed occupancy at the study site is around 95%, $<85\%$ is not likely to reflect access block. Information on inpatient admission was available from Patientliggaren[®] as a dichotomous variable. Unplanned 72h revisits were

defined as revisits within 72 hours of initial visit, to the study site or to the nearby ED of Ängelholm General Hospital, and not marked as a planned revisit in Patientliggaren[®]. Sex (female/male), triage category (1-2 vs 3-4) and high ED input were coded as dichotomous variables. The triage dichotomy reflects medical urgency (i.e., priority 1 and 2 patients were considered “time-sensitive” as they were to be seen by a physician within 15 minutes). High ED input was indicated by a number of patients presenting to the ED during an 8-hour shift (adjusted for time of week) exceeding the 75th percentile. Time of year (Jun-Aug, Dec-Feb vs remainder), time of week (Mon, Sat-Sun vs remainder), and time of day (00:00-08:00, 08:00-16:00, 16:00-00:00) were constructed as three-level categorical variables.

Crude analysis

Fisher’s exact test was applied to compare crude proportions experiencing an outcome at different levels of occupancy. ED length of stay (EDLOS) was compared across strata of in-hospital bed occupancy (for patients who were not admitted to an inpatient ward during their index visit), using the Kruskal-Wallis test (stratified by triage priority). The recent controversy regarding non-parametric tests for skewed distributions in large datasets [20] warranted control using the parametric counterpart (ANOVA).

Multivariate analysis

Logistic regression was applied in a multivariate analysis to adjust for confounders/covariates in inpatient admission and 72h revisits. Directed acyclic graphs (DAGs) were used to construct causal models and to identify covariates to

adjust for in the multivariate analysis (adjustment set) (see supplemental digital content 1-2) [21-23]. The minimally sufficient adjustment set for addressing the total effect of admission and unplanned 72h revisits was time of year, time of week and time of day. The adjustment set was entered into the logistic equation using the entry method. Interaction terms included were based on empirical knowledge and comprised in-hospital bed occupancy*time of day. Interaction terms of weaker association than $p=0.05$ with the outcome were omitted from the model. Adequacy of expected cell counts was assessed in contingency tables [24]. Multicollinearity was addressed by VIF and tolerance statistics. Age and in-hospital bed occupancy were screened for linearity in the logit using the Box-Tidwell approach [24]. If violated, they were transformed to the ordinal scale. Multivariate outliers were addressed by Mahalanobis distance and evaluated on an χ^2 distribution at the $p=.001$ level. In order to improve face validity, we subjected each multivariate model to a sensitivity analysis in two steps (hereafter, step 2 and step 3). In step 2, the adjustment set in step 1 was expanded with triage priority, age and sex. In step 3, it was further expanded with a variable indicating entry via primary triage, a variable indicating the year 2013 (captures introduction of RETTS[®] triage, a clinical observation unit and Hs-troponin) and the variable indicating high ED input. The decision of which variables to include in the sensitivity analyses was based on the causal models and prior knowledge of risk factors for inpatient admission and revisits at the study site [6-7]. A decision to not include triage priority, whether the patient entered the ED via primary triage and high ED input in the multivariate analyses for 72h revisits, was made prior to analysis. The reason was that these factors were only available at index and do not necessarily reflect progress of the condition within 72 hours of discharge. Model

fit was evaluated with the likelihood-ratio test and effect-size with Nagelkerke's R^2 . The likelihood-ratio test and the Wald test were used to evaluate the contribution of individual variables [24]. Dispersion parameters were computed and were used to rescale the Wald statistic as appropriate [24]. Standardized residuals were used to address influential cases. Statistical analyses were performed in the Statistical Package for the Social Sciences[®] version 22 (IBM).

RESULTS

Study subjects

64,909 visits to the EM and internal medicine specialty units were made at the study site in 2011-2013. 12,755 cases presented with non-traumatic chest pain, according to Patientliggaren[®]. 13 cases <18 years of age were excluded, along with 4 cases who died in the ED, 231 cases who left against medical advice and 284 cases who were transferred to another hospital. This left a study population of 12,223 cases.

Missing data

Missing data were only present in the variable indicating triage priority (37/12,223=0.3%). The scant number warranted exclusion of the missing cases in the multivariate analysis and in the comparison of EDLOS stratified by triage priority.

Unadjusted results

	Outcome		
	Inpatient admission	72h revisit	72h revisit, admitted
Triage priority 1	351 (87.5%)	3 (6%)	1 (2%)
Triage priority 2	2,452 (63.6%)	70 (5.0%)	28 (2.0%)
Triage priority 3	2,527 (34.1%)	186 (3.8%)	52 (1.1%)
Triage priority 4	86 (16.4%)	19 (4.3%)	7 (2%)
Missing priority	11 (29.7%)	2 (8%)	0 (0%)
Age 18–40 years	272 (12.8%)	58 (3.1%)	10 (0.5%)
Age 40–65 years	1,843 (38.3%)	137 (4.6%)	42 (1.4%)
Age 65–80 years	1,969 (58.5%)	65 (4.7%)	25 (1.8%)
Age >80 years	1,343 (70.2%)	20 (3.5%)	11 (1.9%)
Male	3,130 (47.5%)	168 (4.8%)	59 (1.7%)
Female	2,297 (40.8%)	112 (3.4%)	29 (0.9%)
Dec–Feb	1,325 (41.7%)	59 (3.2%)	18 (1.0%)
Sep–Nov, Mar–May	2,685 (43.8%)	147 (4.3%)	50 (1.4%)
Jun–Aug	1,417 (48.6%)	74 (4.9%)	20 (1.3%)
Mon	887 (42.3%)	49 (4.1%)	21 (1.7%)
Tue–Fri	3,203 (45.4%)	156 (4.0%)	46 (1.2%)
Sat–Sun	1,337 (43.6%)	75 (4.3%)	21 (1.2%)
00:00 – 08:00	1,203 (49.1%)	55 (4.4%)	16 (1.3%)
08:00 – 16:00	2,464 (45.8%)	94 (3.2%)	31 (1.1%)
16:00 – 00:00	1,760 (40.1%)	131 (5.0%)	41 (1.6%)
≥100% occupancy	1,277 (44.6%)	50 (3.2%)	21 (1.3%)
95–100% occupancy	N/A	79 (3.9%)	N/A
0–95% occupancy	N/A	151 (4.7%)	N/A
<100% occupancy	4,150 (44.3%)	N/A	67 (1.3%)
Total	5,427 (44.4%)	280 (4.1%)	88 (1.3%)

Table 1. Descriptive data of the study population across study outcomes

Crude analyses revealed no significant differences regarding the proportion of patients being admitted to hospital at occupancy <100% compared to at ≥100% (44.3% vs 44.6%) (p=.797). The proportion revisiting within 72 hours was lower at higher levels of occupancy (3.2% at ≥100% occupancy vs 4.7% at <95% occupancy) (p=.033). This difference was not significant after applying the Bonferroni correction. No difference in the proportion revisiting and being

admitted was revealed ($p=.899$). EDLOS was significantly longer for patients who were discharged from the ED at times of high in-hospital bed occupancy than otherwise ($p=.001$). This remained true for triage priority 1-2 ($p=.0001$) after stratifying by this variable.

	Triage priority								Total			
	1-2 (N=1,452) (p=.0001)				3-4 (N=5,318) (p=.114)				(N=6,796) (p=.001)			
Occupancy [%]	<95	95-100	100-105	≥105	<95	95-100	100-105	≥105	<95	95-100	100-105	≥105
EDLOS [h] (IQR)	3.04 (2.10-4.32)	3.08 (2.12-4.83)	3.32 (2.49-4.76)	4.10 (2.57-5.45)	3.03 (2.10-4.40)	3.12 (2.07-4.38)	3.07 (2.05-4.40)	3.46 (2.25-4.68)	3.03 (2.10-4.37)	3.12 (2.07-4.45)	3.13 (2.15-4.55)	3.55 (2.32-4.75)

Table 2. Median emergency department length of stay (EDLOS) in relation to occupancy, stratified by triage priority (26 cases missing)

Adjusted results

Age violated the assumption of linearity in the logit and was transformed to the ordinal scale (18-40, 40-65, 65-80 and >80 years). Cut-offs were determined prior to analysis and were based on perceived clinical relevance. 40-65 years was used as reference. Hospital occupancy passed the test for linearity in the logit and was included in its continuous form. Cell counts were below 5 for occupancy <85% and >105%, and models are therefore considered most reliable in the interval 85-105% occupancy. The number of events for 72h revisits resulting in admission was <10 for the adjustment sets specified in steps 2 and 3; hence, only step 1 of the multivariate analysis was pursued for this outcome.

Outcome	Adj. set	Reg. coeff	SE	Wald chi ²	p	OR	95% CI for OR	
							Lower	Upper
Admission	Step 1	-0.012	0.004	9.425	.002	0.988	0.981	0.996
	Step 2	-0.013	0.004	9.643	.002	0.987	0.979	0.995
	Step 3	-0.014	0.004	10.823	.001	0.987	0.979	0.995
72h revisit	Step 1	-0.016	0.010	2.499	.114	0.984	0.964	1.004
	Step 2	-0.017	0.008	4.805	.028	0.983	0.968	0.998
	Step 3	-0.017	0.007	5.374	.020	0.983	0.969	0.997
72h revisit, admitted	Step 1	0.010	0.014	0.549	.459	1.011	0.983	1.039

Table 3. Odds ratio (OR) for outcome per percent increase in in-hospital bed occupancy via logistic regression, adjustment sets 1-3

The original multivariate model as well as the sensitivity analysis revealed a significant negative association between the in-hospital bed occupancy and the odds of inpatient admission (see table 3 for details). A negative association was found between the exposure and 72h revisits in step 2 and 3 of the model addressing this outcome, however, the strength of this association was not significant if applying the Bonferroni correction. A greater number of multivariate outliers and larger residuals than expected were observed in the models addressing 72h revisits, which indicates that some variables that are strong predictors of the outcome were not included in the models. The odds ratios (ORs) for admission at 5% increments relative to 95% occupancy are displayed in figure 1.

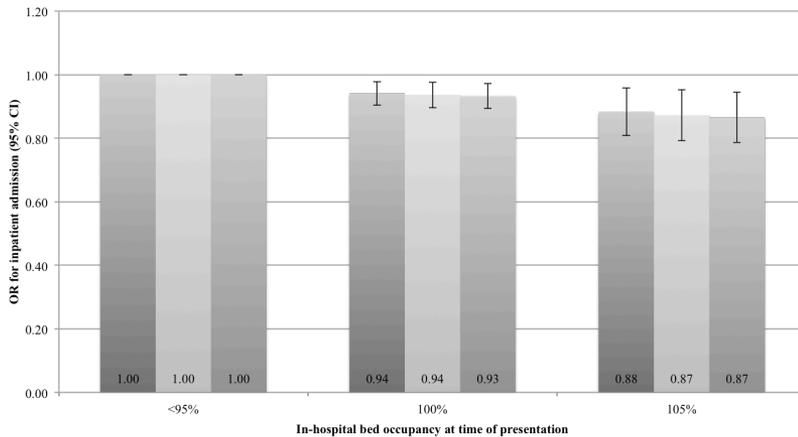


Figure 1. Odds-ratio of inpatient admission at different levels of access block, with 95% in-hospital bed occupancy used for reference, adjustment sets 1-3

DISCUSSION

Study results support the hypothesis of that patients with chest pain are less likely to be admitted to a hospital bed, at times of access block than otherwise. In terms of magnitude, the effect was attenuated compared to in the undifferentiated ED population at the study site [6]. This may reflect heterogeneity in the tendency to admit patients with different main complaints (which appeals to logic, since different complaints suggest underlying conditions of varying severity). The attenuation could also reflect the longer time period covered in this work (2011-2013, compared to 2011-2012). Empirical knowledge suggests that access block was more prevalent in 2013, which may have institutionalized the management of some subgroups of low risk chest pain patients, so that they were less often admitted in 2013 than in 2011-2012 (when the management could have been subject to more variation). The significantly longer EDLOS observed at times of access block may reflect that ED staff increasingly performed necessary evaluation and treatment in the ED, in order to avert hospital admissions. It could also suggest longer waiting times for diagnostics and treatment in the ED, and

given that some of the underlying conditions in the patient population are time-sensitive, this could be of detriment to patients. The decreased revisit rate observed could either be explained by alternative management strategies, where time-sensitive conditions were ruled out and ED staff arranged suitable follow-up appointments that reduced the need for subsequent ED visits, or by that patients sought care at other facilities than the two EDs captured in the study. A decreased 72h revisit rate could also be observed if a greater proportion of patients die at home, shortly after ED discharge. Future studies should include more granular endpoints (such as mortality) in the patients discharged from the ED, as well as more detailed data about which procedures and interventions were performed in the ED, in order to clarify whether the observed effect reflects an increased risk-taking in ED staff at times of access block. Moreover, enrolling patients from several hospitals in the region would increase the statistical power to a level that allows for more thorough subgroup analysis as well as a higher external validity of the results.

Conclusion

Study results suggest that ED patients with chest pain are less likely to be admitted to a hospital bed at times of access block than otherwise. Future studies need to address rare (but severe) outcomes such as mortality, in order to clarify whether the observed effect reflects increased risk taking in ED staff when inpatient beds are not available.

AUTHORS' CONTRIBUTIONS

MB participated in writing the study protocol, merging the datasets, the statistical analyses and the final writing of the manuscript. KI, MLO and FJ participated in developing the causal models and in commenting on the manuscript.

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CONFLICTS OF INTEREST

KI was the head of the division responsible for the emergency department where the study was conducted. FJ is currently the chair of that emergency department. All other authors declare that they have no conflicts of interest with the study.

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Paper V

**Patients are not increasingly denied admission to the emergency department
at times of access block - a retrospective cohort study.**

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ABSTRACT

Background

Emergency department (ED) overcrowding is frequently described in terms of input- throughput and output. Impaired ED output, or access block, is often cited as the most important cause of ED overcrowding. In order to reduce ED input, a concept called primary triage has been introduced in several Swedish EDs. In short, primary triage is a facility where a specially trained nurse separately evaluates patients who present at the emergency department (ED) in order to sort out the less acute cases and refer them to another level of care (e.g. primary care). The aim of the present study was to elucidate whether patients were more likely to be denied admission to the ED by primary triage, at times of access block. The appropriateness of discharges from primary triage was assessed by 72h revisits to the ED.

Methods

The study was conducted as a retrospective cohort study on administrative data from the ED at a 420-bed hospital in southern Sweden from 2011-2012. Access block was defined in terms of hospital occupancy. In addition to crude comparisons of proportions experiencing each outcome across strata of hospital occupancy, multivariate models were constructed in order to adjust for age, sex and other factors.

Results

A total of 37,129 visits to primary triage were included in the study. 53.4% of these were admitted to the ED. Among the cases referred to another level of care,

8.8% made an unplanned revisit to the ED within 72 hours. The permeability of primary triage was not lower at higher levels of in-hospital bed occupancy.

Rather, patients were more likely to be admitted to the ED when hospital occupancy was 100-105% compared to <95%, OR 1.09 (95% CI 1.02-1.16). No significant association between access block and the probability of 72h revisits was observed.

Conclusions

Patients assessed in primary triage were less, rather than more, likely to be denied access to the ED during periods of access block. This may reflect the primary triage nurses' desire to err on the safe side by increasingly admitting patients to the ED when their workload was high.

Keywords (MeSH): “Emergency medicine,” “Bed occupancy,” “Emergency Department revisits,” “triage”, “fast-track”

BACKGROUND

Emergency Department (ED) overcrowding has received considerable attention in the literature. [1-3] ED overcrowding is defined as a situation where the need for emergency services exceeds available resources, and its causes have been divided into input, throughput and output factors [4], of which the last have been suggested to be the most influential [1,5]. We recently showed that scarcity of inpatient beds (i.e., access block or “hospital crowding”) is not only associated with an increased ED length of stay (EDLOS) [6], but also that ED patients are less likely to be admitted to a hospital bed during access block [7,8].

Several strategies aimed at reducing ED overcrowding through managing ED input- and throughput factors have been proposed [9]. These include fast-track service lines [9-10], adding a physician to triage [10-13], test ordering by nurses [9-10, 14-15] and introducing primary care professionals to hospital EDs [16]. Other strategies aim at improving discharge planning and follow-up for patients with chronic diseases [17-19], and still others are directed at diverting patients of perceived low acuity away from the ED [20]. In order to decrease the inflow of non-urgent patients to the ED, a similar strategy has been implemented in Region Skåne in southern Sweden. The concept is called “primary triage” and means that a specially trained nurse separately evaluates patients who present at the emergency department (ED) in order to sort out the less acute cases and refer them to another level of care (e.g. primary care). Despite what the name of the facility suggests, its purpose should not be confused with what is usually meant by the term triage (i.e, stratifying patients by risk in order to help the ED physician prioritize). The aim of the present study was to evaluate whether

patients were more likely to be triaged out of the ED at times of access block than otherwise. The appropriateness of discharges from primary triage was assessed by the 72h revisit rate.

METHODS

Study design

The study was conducted as a retrospective cohort study on administrative data from the ED at a 420-bed emergency hospital in southern Sweden.

Inclusion criteria

All patient visits registered in the ED information system Patientliggaren[®] at Helsingborg general hospital in 2011-2012 and who were assessed in primary triage were included in the study.

Sample size calculation

In order to limit bias, the study material was not subject to further restrictions. Access block was defined in terms of hospital occupancy. *Post hoc* power calculations were performed to determine the number of strata (see cut-offs in the “variables” section) of hospital occupancy to use for group comparisons ($\alpha = 0.05$, $1-\beta = 0.80$) [21]. Absolute differences of 5% in the proportion of patients admitted to the ED and 2% in the proportion of patients revisiting were considered clinically relevant for study purposes. Sample sizes allowing for 10 events per predictor were considered appropriate for multivariate analysis [22].

Setting

Helsingborg general Hospital is one of four hospitals providing emergency care in Region Skåne in southern Sweden. Its ED serves a population of around 250,000, which expands to more than 300,000 in the summer due to tourism. It is an academic teaching hospital, providing education for medical students and Emergency Medicine residents. The annual ED census is around 60,000, with approximately 15% of patients arriving by ambulance.

Upon arrival to the ED, patients are registered in the information system Patientliggaren[®]. Until 1st January 2012, registration was performed by a nurse in the “spot-check” facility. This nurse did not measure vital parameters or conduct any physical examination, beyond recording the main complaint and a short anamnesis. The spot-check nurse could refer patients either directly to the ED, or (if their complaint was considered benign) to primary care without further assessment in the ED. If unsure whether the patient belonged in primary care or should be assessed in the ED, the nurse could refer patients to primary triage, situated in the same physical facilities as the ED. Primary triage was staffed by a nurse who was able to conduct physical examinations and order laboratory tests. Beginning January 1, 2012, the task of initial registration was delegated to a secretary and the spot-check facility ceased to be. The secretary could not refer patients to primary care, but was limited to admitting patients directly to the ED or referring them to primary triage. Strict guidelines were developed for the secretary to follow (table 1). After evaluating patients, the nurse in primary triage could admit them to the ED, refer them to primary care or discharge them home. To aid her decision, the decision-support “Triagehandboken” [23] was available

in print and electronically. Nurses in primary triage could consult an ED physician when in doubt, but no physician was on duty in primary triage. Primary triage nurses could be asked to assist staff inside the ED during the entire study-period. Primary triage could also be bypassed at times it was experiencing long queues. Even though the name suggests otherwise, the main task of primary triage should not be confused with the risk stratification performed by conventional triage nurses (which is what is performed in secondary triage at the study site). Patients who were referred to the ED by a physician were directly admitted to the ED after registration and hence bypassed primary triage. Patients arriving by ambulance were admitted to the ED directly (see appendix 1 for a schematic picture of the ED front-end organization). Patients who were referred to primary care from spot-check or from primary triage were guaranteed a medical evaluation by a nurse in primary care the same day or the day after (depending on hours of primary care availability, generally until 5pm). One primary-care facility would accept patients outside office hours (until 8pm), but was located 15 minutes away from the ED by car. Patients often resented primary triage nurses' advice to contact this facility.

<p>All the criteria below need to be fulfilled before a patient can be referred to primary triage</p> <p>Age >1 and < 70 Fully awake, without dyspnoea, pallor or sweatiness Self-ambulating without problems 5 or fewer patients waiting for primary triage</p> <p>Each of the following groups of patients is directly admitted to the ED after registration</p> <p>Dyspnoea Chest pain Abdominal pain Patients with known cancer Foreign body Known atrial fibrillation (where the patient suspects relapse) Chronic bowel disease Problems related to nasogastric tubes, catheters and plasters Scrotal pain Urinary obstruction or haematuria Revisits (planned and unplanned)</p>
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Table 1. Criteria to be fulfilled in order to be directed to primary triage by the secretary

After being admitted to the ED, patients underwent secondary triage (an algorithm for prioritizing the acuity of a patient’s main complaint that helps the physician prioritize which patient to attend to first, similar to what is meant by the word in most EDs worldwide). During the study period, the 4-level triage system “medical emergency triage and treatment system” (METTS) was used in secondary triage [24-25]. From secondary triage, patients were directed to separate units for surgery, orthopaedics, internal medicine, otolaryngology, gynecology, paediatrics, ophthalmology and psychiatry in a triage-to-specialty model. A complementary unit staffed by emergency physicians capable of handling various complaints, except for psychiatric, otolaryngologic, ophthalmologic and paediatric (medicine) complaints, was introduced in 2010 and operates from 8am to 11pm daily.

Data sources

Data on hospital occupancy was retrieved from an occupancy database used by hospital management for quality assurance activities. Occupancy was measured as

the number of occupied beds divided by the number of available beds (i.e., staffed beds) in the hospital. The data source was the hospital administrative system used for billing (PASiS). The database was updated at the beginning of every hour by an application developed by the hospital informatics unit (QlikView[®] software). Individual level data on ED visits was retrieved from the ED information system Patientliggaren[®]. Data gathering and linking were performed by the hospital informatics unit using QlikView[®] software. No system crashes were reported during the study period.

Statistics

Post hoc power calculations revealed that the study sample was large enough to detect the pre-specified differences for strata of hospital occupancy of <95%, 95-100%, 100-105% and $\geq 105\%$ for ED admissions and <95%, 95-100% and $\geq 100\%$ for 72h revisits. Strata were proposed prior to analysis. Hospital occupancy <85% has traditionally been used for bed capacity planning, following Bagust et al [26]. Since the mean bed occupancy at the study site is around 95%, <85% is not likely to reflect access block and hence <95% was selected as a common sense reference. Proportions of patients experiencing each outcome were compared across strata using Fisher's exact test.

Binary logistic regression models were constructed in order to adjust for the effects of other factors that may influence the outcome. Also, a sensitivity analysis was performed, using occupancy as measured 3 hours prior to patient presentation (rather than at presentation) at the ED as the exposure. This time interval was proposed prior to analysis. Variables included in the models were: sex, age group

(0-1 year, 1-18 years, 18-40 years, 40-70 years and ≥ 70 years), shift (0am-8am, 8am-4pm, 4pm-0am), day of week (Mon, Tue-Fri, Sat-Sun), registration by a spot-check nurse (rather than a secretary) upon arrival, presentation on a shift with many visits (high inflow) to primary triage and presentation on a shift with high inflow to the ED. The decision on age intervals was based on the fact that patients < 1 year and ≥ 70 years were referred directly into the ED without passing primary triage, according to the guidelines followed by the secretary who replaced the “spot-check” nurse in January 2012. The same occupancy levels as in the crude analysis were used in the multivariate models. Presentation on a shift with high inflow was constructed as a dichotomous variable, indicating presentation on one of the 25% of shifts subject to most visits (adjusted for shift type). Hospital occupancy and age were considered for inclusion in the models as continuous variables, but both violated the assumption of linearity in the logit and were therefore included as the ordinal variables described above [27]. Multicollinearity testing was performed using tolerance and VIF statistics. Independent variables were manually added to the models, rather than stepwise, in order not to exclude clinically relevant variables [28]. Model fit was evaluated through Nagelkerke’s R^2 . The association between each predictor and the outcome was addressed by the -2LL and the Wald statistics. Models were screened for influential cases by addressing standardized residuals. The relatively large number of comparisons warranted application of the Bonferroni correction, yielding a level of significance of $p=0.006$. Statistical analyses were performed in IBM® SPSS® Statistics 22. Data was anonymized before analysis. The Regional Ethical Review Board in Lund granted ethical approval for the study, dnr 2013/11.

RESULTS

160,462 visits were registered in Patientliggaren[®] 2011-2012. 37,129 visits were evaluated in primary triage and 19,829 (53.4%) of these were admitted to the ED. Of the 17,300 cases discharged from primary triage, 1,529 (8.8%) made an unplanned revisit to the ED within 72 hours.

Crude analysis

The proportion of visits to primary triage that resulted in admission to the ED was 52.3% at hospital occupancy <95%, 53.5% at 95-100%, 56.0% at 100-105% and 57.3% at occupancy \geq 105% ($p < .001$). *Post hoc* power analysis indicated that the crude analysis did not have sufficient power to establish the detected difference between occupancy 95-100% and the reference category. Using the occupancy as measured 3 hours prior to patient presentation yielded the following proportions: 52.6% admitted to the ED at occupancy <95%, 53.7% at 95-100%, 54.8% at 100-105% and 55.9% at \geq 105% ($p = .003$). *Post hoc* power analysis indicated that the crude analysis did not have sufficient power to establish the difference between either occupancy 95-100% or \geq 105% and the reference category.

Among the 17,300 cases who were discharged from primary triage, the proportion of unplanned revisits to the ED within 72 hours was 8.8% at occupancy <95%, 9.0% at 95-100% and 8.7% at \geq 100% ($p = .885$). Using the occupancy as measured 3 hours prior to patient presentation yielded proportions of 9.4% at occupancy <95%, 8.2% at 95-100% and 8.2% at \geq 100% ($p = .020$). *Post hoc* power calculations indicated that the crude analysis did not have sufficient power to

establish these differences. Basic descriptive statistics across each of the outcomes are shown in table 2.

		ED admission (N=37,129)		72h revisits (N=17,300)	
		Discharged	Admitted	Discharged	Admitted
Sex	Female	8,232 (45.8%)	9,745 (54.2%)	7,541 (91.6%)	691 (8.4%)
	Male	9,068 (47.3%)	10,084 (52.7%)	8,230 (90.8%)	838 (9.2%)
Age [Years]	0-1	82 (46.3%)	95 (53.7%)	79 (96.3%)	3 (3.7%)
	1-18	3,028 (46.1%)	3,545 (53.9%)	2,797 (92.4%)	231 (7.6%)
	18-40	8,278 (52.5%)	7,478 (47.5%)	7,590 (91.7%)	688 (8.3%)
	40-70	5,071 (42.1%)	6,972 (57.9%)	4,559 (89.9%)	512 (10.1%)
	>70	841 (32.6%)	1,739 (67.4%)	746 (88.7%)	95 (11.3%)
Year	2011	8,942 (44.8%)	11,032 (55.2%)	8,098 (90.6%)	844 (9.4%)
	2012	8,358 (48.7%)	8,797 (51.3%)	7,673 (91.8%)	685 (8.2%)
High volume input	p-triage	5,786 (45.1%)	7,037 (54.9%)	5,234 (90.5%)	552 (9.5%)
	ED	3,935 (44.4%)	4,935 (55.6%)	3,598 (91.4%)	337 (8.6%)
Shift	8am-4pm	6,216 (45.3%)	7,500 (54.7%)	5,753 (92.6%)	463 (7.4%)
	4pm-0am	8,502 (49.0%)	8,859 (51.0%)	7,784 (91.6%)	718 (8.4%)
	0am-8am	2,582 (42.7%)	3,470 (57.3%)	2,234 (86.5%)	348 (13.5%)
Day of week	Mon	2,538 (47.5%)	2,810 (52.5%)	2,325 (91.6%)	213 (8.4%)
	Tue-Fri	8,510 (46.0%)	9,972 (54.0%)	7,789 (91.5%)	721 (8.5%)
	Weekend	6,252 (47.0%)	7,047 (53.0%)	5,657 (90.5%)	595 (9.5%)

Table 2. Descriptive data of the study population across study outcomes

Adjusted analysis

All independent variables screened for inclusion in the multivariate models were included in the preliminary primary effects models. The interaction term of in-hospital bed occupancy*high ED inflow was significantly associated with the outcome in both models addressing the proportion admitted to the ED. This warranted stratification by high ED inflow, in addition to the analysis with the interaction term omitted.

Neither of the analyses indicated problems with multicollinearity or multivariate outliers. The odds-ratio (OR) for ED admission for different levels of the

exposure variable is shown in figures 1-2. The only significant difference in ED admission was found at occupancy 100-105% compared to <95%, with OR 1.09 (95% CI 1.02-1.16). This effect did not remain in the sensitivity analysis. After stratifying for high ED inflow, the effect was detectable in both the main analysis and the sensitivity analysis, for shifts not experiencing high ED inflow, with 95% CI for OR 1.06-1.24 and 1.01-1.18 respectively.

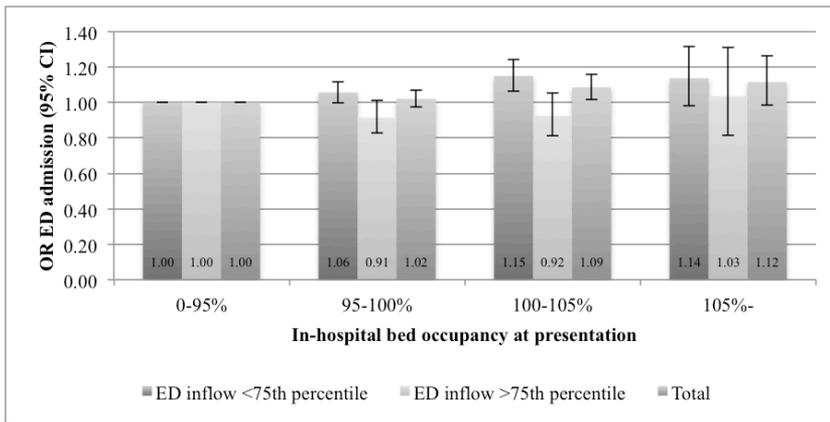


Figure 1. Adjusted analysis. Odds-ratio for ED admission, compared to occupancy <95% (measured at presentation)

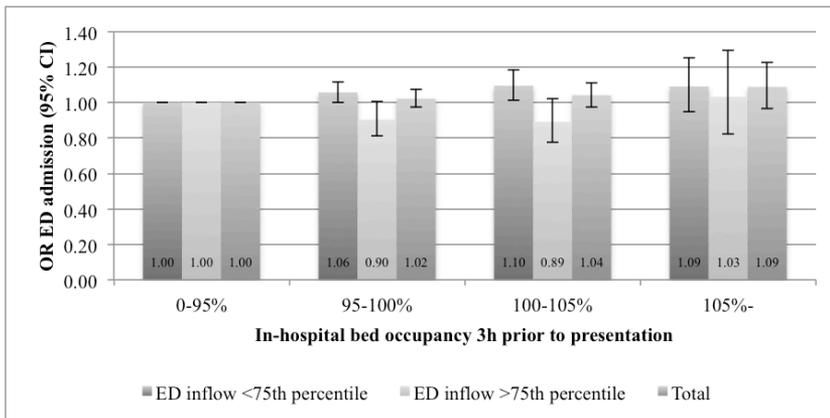


Figure 2. Adjusted analysis. Odds-ratio for ED admission, compared to occupancy <95% (3h timelag)

Neither model addressing ED admission displayed any large standardised residuals. No significant differences in 72h revisits were revealed in any of the models (see figures 3-4). The models addressing 72h revisits displayed some large residuals, which indicates that variables not available to us influenced the likelihood of 72h revisits. This is supported by a small effect size.

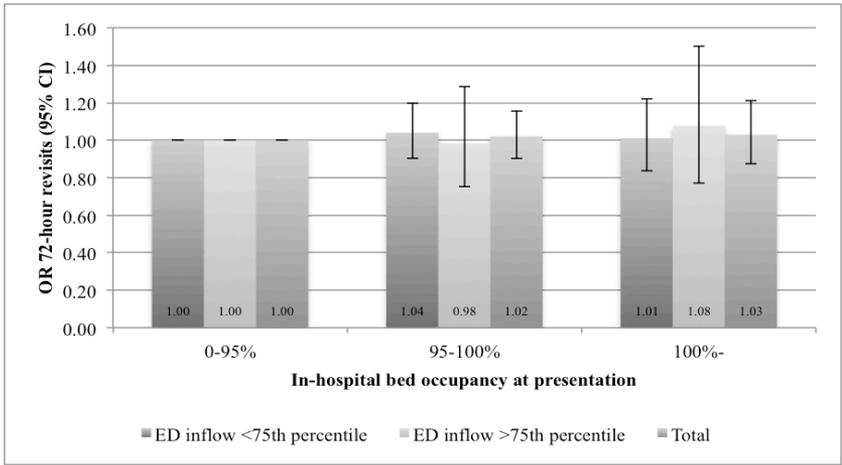


Figure 3. Adjusted analysis. Odds-ratio for 72h revisit, compared to occupancy <95%. (measured at presentation)

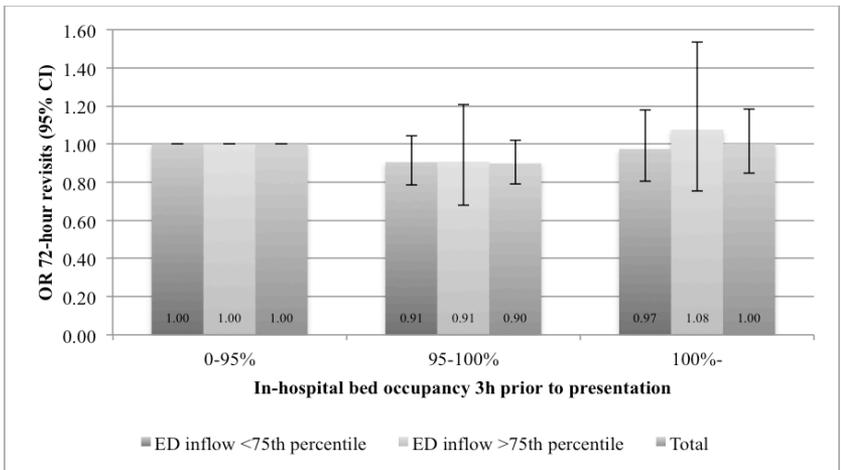


Figure 4. Adjusted analysis. Odds-ratio for 72h revisit, compared to occupancy <95%. (3h timelag)

DISCUSSION

The study results suggest that patients assessed in the primary triage facility were less, rather than more, likely to be triaged out of the ED at times of access block than otherwise. The effect was observed for occupancy measured at patient presentation as well as 3 hours prior. The crude analysis revealed an increased permeability of primary triage at occupancy $\geq 105\%$ and at 100-105% compared to at $< 95\%$. Even though these differences were smaller than what was considered clinically meaningful prior to conducting the study, the *post hoc* power analysis revealed adequate statistical power and the findings deserve elaboration. It is possible that the results reflect a situation occurring when nurses in primary triage were asked to assist ED staff at times of high workload. The proposed causal chain is then that, when their workload was high, nurses in primary triage tended to err on the safe side by admitting patients to the ED, rather than to triage them out of the ED. This interpretation is supported by the attenuation of the effect, when high ED input was adjusted for in the multivariate models (i.e. most of the effect observed in the crude analysis was caused by high ED workload on shifts subject to high ED input). This appeals to logic, since it means that resources (i.e. the primary triage nurses) were directed to the sicker patients in the ED, rather than to the relatively healthy patients in primary triage when the ED workload was high. The effect of bypassing primary triage altogether could not be measured in the present study, since such cases could not be separated from cases directly admitted to the ED for other reasons.

Limitations to study power caused the collapsing of occupancy-strata when addressing 72h revisits, but the analysis was able to detect differences in the

proportion revisiting the ED of 2% and larger with sufficient statistical power. The lack of a significant association between in-hospital bed occupancy and the proportion of 72h revisits suggests that the appropriateness of discharges from primary triage was not severely affected by access block. This would be in line with the main findings, which suggested that patients were rather admitted to the ED than discharged from primary triage when access block prevailed. However, the proportion of patients that made a revisit after being referred to another level of care by primary triage was relatively high (8.8%), calling the appropriateness of triaging patients out of the ED into question.

Since registration in Patientliggaren[®] was mandatory for all patients entering the facility, differential losses of data are unlikely. This is supported by the absence of system crashes during the study period. It should be noted that only 72h revisits to the study site were identified in the analysis, and that patients may have presented to other EDs in the region. However, the overlap of ED catchment areas is smaller than in urban areas in e.g. the U.S. (i.e. patients do not have that many alternatives) and this group is therefore anticipated to be small. The single-centre approach affected the generalizability of study findings, especially to areas where legislation (e.g., U.S. EMTALA) prohibits diversion from the ED without medical screening. Even though strategies to reduce ED input by diverting patients to other levels of care may become less popular internationally [29], they are fairly common practice in Sweden still. While some patients presenting in the ED may indeed do so inappropriately, the authors believe that using primary triage nurses to divert patients away from the ED constitutes suboptimal use of

resources, which instead should be allocated to the patients that need them the most (i.e. the sickest patients in the ED).

Conclusion

The study results indicate that patients were less likely to be triaged out of the ED at times of access block than otherwise. This may reflect the redirecting of resources from the ED front end sorting facility to the sicker patients in the ED. The results are reassuring, since at times of high workload, staff tended to err on the safe side and admitted more patients to the ED, rather than took potential risks by triaging them out of the ED.

COMPETING INTERESTS

KI was the head of the division responsible for the Emergency Department where the study was conducted. FJ is currently the chair of the Emergency Department where the study was conducted. All other authors declare that they have no competing interests in relation to the study.

AUTHORS' CONTRIBUTIONS

MB, MLO and KI all participated in developing the study design. LG collected and concatenated data. MB performed the statistical analyses, with support from professional biostatisticians. MB prepared all versions of the manuscript. FJ, MLO, KI and KE participated in drafting the manuscript.

AUTHORS' INFORMATION

KI was the head of the division responsible for the Emergency Department where the study was conducted. FJ is the chair of the Emergency Department where the study was conducted. MLO is the main supervisor for MB and KE, who are both PhD students at Lund University. KE is an intern physician and MB is a resident physician in internal medicine. LG is a controller in the informatics department of the hospital where the study was conducted.

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