QUEEN MARY UNIVERSITY OF LONDON

A thesis submitted for the degree of Doctor of Philosophy

Improving Trauma System Effectiveness Through Optimisation of A Major Trauma Triage Tool

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Final Submission 31st October 2023

Preliminary Contents

Statement of originality

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Acknowledgments

I would like to thank my supervisors Professor Karim Brohi and Professor Elaine Cole for giving me the opportunity to be a part of the Centre for Trauma Sciences and pursue my own area of research interest with all the necessary guidance and support along the way.

My fellow research fellows, research assistants and TARN clerical staff at the Royal London Hospital and within the Blizard Institute that I had the pleasure of sharing desk space with during my 3-year research period. We shared ideas, laughter and despair and I value the lasting friendships that have come about from it. I wish to thank especially Mr Simon Glasgow for his invaluable input in helping me to develop and refine the triage tool model.

Dr Rachael Fothergill and her colleagues at CARU for facilitating and supporting my work at LAS and Imogen Gunson for her assistance with data collection for TuTOR.

Professors Charles Knowles and Tim Harris for their advice during the 9-month and 18-month review stages of my PhD.

My Educational and Clinical supervisors who continued to support me during my return to training and clinical work whilst juggling my thesis write-up, namely Mr Martin Griffiths, Mr Ross Davenport, Mr Nigel Tai, Mr Pranav Somaiya, Mr Chris Chan, Mr Dip Mukherjee and Mr Pratik Sufi.

Lastly and most importantly my family. My parents, siblings and in-laws for the type of endless support that I can always count on. My kids, Kaima, Kora (who was born at the outset of my PhD!) and Kamara for inspiring me every day and most of all my wonderful wife Urenna whose patience has been remarkable and whose love and support I have relied on daily.

Associated presentations and awards

Presentations

Sept 2019	*Outcomes in Isolated TBI: There's More To It Than Right Place, First Time* Podium presentation- AAST 2019 Annual Meeting, Dallas, USA *Optimising Prehospital Triage In An Inclusive Urban Trauma System* Podium presentation- AAST 2019 Annual Meeting, Dallas, USA *Triage in the Trauma System* Podium presentation- Royal London Hospital ‘‘TRAUMAtalks’ lecture series
April 2019	*Triage decision in severe traumatic brain injury: Does initial level of care adversely affect patient outcomes* Poster presentation- Blizard Institute Graduate Studies Day, Queen Mary University of London
July 2018	*Optimising Trauma Triage Tools: A Model for Wider Surgical Care* Poster presentation- Royal College of Surgeons Research Fellowship viva day
June 2018	*Does prehospital triage predict patient outcomes?* Podium presentation- *London Trauma Symposium*
October 2017	*Triage decision in severe traumatic brain injury: Does initial level of care adversely affect patient outcomes* Poster presentation- William Harvey Day research meeting, Queen Mary University of London

Grants and Awards

July 2019	$2000 (equivalent)	AAST International Relations Committee Travel Scholarship
July 2019	£200	Barts and The London School of Medicine and Dentistry Travel Grant
June 2019	£1000	QMUL Postgraduate Research Fund
June 2019	£750	Blizard Institute Funds

Abstract

Background: A large and growing body of evidence supports the reconfiguration of trauma services into organised regional systems of care. The London Major Trauma System was the first in the UK and became operational in 2010 comprising of networks of specialised Major Trauma Centres (MTCs) which are equipped to treat the most severely injured patients in a timely manner, and nearby Trauma Units (TUs) which are appropriately set up to manage less severely injured patients. Ambulance crews utilise standardised triage tools to determine the appropriate destination of patients. At present large volumes of trauma present at a limited number of MTCs. This may have an adverse impact on the care provided to trauma and non-trauma patients at MTCs alike.

Aims: The overall aim of this study was to optimise the London Trauma Triage Tool to better distinguish between patients requiring MTC-level care and those who could be safely taken to TUs. To achieve this, two studies which utilised trauma registry data and a third simulation modelling study were conducted. Firstly a retrospective cohort study of over 5000 patients with isolated traumatic brain injuries (TBI) was conducted to compare the outcomes of patients who were initially triaged to MTCs against those triaged to TUs both in the cases of patients who required neurocritical intervention and those who only needed conservative treatment. A second cohort study matched over 1200 London Ambulance Service and UK trauma registry records to identify the aspects of the triage tool best suited to identifying patients in need of MTC-level care. Finally, data from the second study was used to build a deterministic algorithm-based simulation model to assess the potential impact of triage tool changes.

Results: Findings from the first two studies supported the notion of reducing the number of patients automatically directed to MTCs by the existing triage tool. For TBI patients, overall adjusted mortality was no greater for patients transferred from a TU to an MTC for neurocritical interventions than if they have been admitted to the MTC directly. For patients requiring only conservative management, no mortality difference was seen between MTC and TU patients. In study 2 weaker performing triage criteria such as ‘injury mechanism’ and certain anatomical injury patters were identified and removed from our new modified triage tool. This new tool and other variations were simulated in the model in study 3 demonstrating the potential for up to 3000 avoided MTC admissions with an average year of trauma volume.

Conclusion: This thesis has shown the potential to increase trauma system inclusivity without significant detriment to patient safety. Furthermore it has the potential to improve patient experience by keeping more people at their local hospital rather than unnecessarily admitting them to regional MTCs. **The newly modified London Trauma Triage Tool came into operation with the London Ambulance Service in March 2020 with plans to formally audit its performance to date.**

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Abbreviations

ACS- American College of Surgeons

AIS- Abbreviated Injury Scale

CARU- Clinical Audit and Research Unit

CC- Critical Care

ED- Emergency Department

EHAAT- Essex and Herts Air Ambulance Trust

EMS- Emergency Medical Services

GCS- Glasgow Coma Scale

HEMS- Helicopter Emergency Medical Service

HRA- Health Research Authority

ICD-10- International Classification of Disease

ICU- Intensive Care Unit

IQR- Interquartile Range

IRAS- Integrated Research Application System

ISS- injury Severity Score

KSSAAT- Kent, Surrey and Sussex Air Ambulance Trust

LAA- London Air Ambulance

LMTS- London Major Trauma System

LOS- Length of stay

MCI- Mass Casualty Incident

MTC- Major Trauma Centre

NHS- National Health Service

NICE- National Institute for Health and Care Excellence

PRF- Patient Report Form

REC- Research Ethics Committee

ROTEM- Rotational Thromboelastometry

RTS- Revised Trauma Score

SD- Standard Deviation

SECAmb- South East Coast Ambulance Service

TARN- Trauma Audit and Research Network

TEG- Thromboelastograhy

TuTOR- Trauma Triage and Outcomes Research

TU- Trauma Unit

TRISS- Trauma Injury Severity Score

NISS- New Injury Severity Score

Chapter 1: Introduction

1.1 Trauma

Trauma is a disease of physical damage resulting from the exposure of the human body to levels of energy (kinetic, thermal, chemical, electrical or radiant) in amounts that exceed the threshold of mechanical/physiological tolerance and/or the impairment of normal function resulting from a lack of oxygen (drowning, smoke inhalation or strangulation) (1). It is important to view trauma as a disease because whilst accidents do happen, it can be argued that trauma is often predictable, and that traumatic injury has an epidemiology and risk factors which may be targeted for primary prevention. According to the most recent World Health Organization figures (2), injuries and violence takes the lives of 4.4 million people globally each year and constitute nearly 8% of all deaths. They are responsible for an estimated 10% of all years lived with disability. For people aged 5-29 years, three of the top five causes of death are injury-related (road traffic injuries, homicide and suicide). Addressing the number of deaths from injury and violence form an important part of several of the United Nations' Sustainable Development Goals.

Risk factors for trauma are numerous but broadly may include alcohol and substance abuse, poverty and societal deprivation, poor healthcare provision, gender inequality, inadequate product safety standards and regulation, poor road safety, geopolitical instability, and inadequate criminal justice systems. All of these can be addressed at all levels of government and society to reduce the risk and impact of traumatic injury.

Whether it be through road safety initiatives or educating and empowering women and children who are most often the victims of violence, the public health approach to tackling the disease of trauma is a crucial aspect of its overall management. In recent years this concept of treating trauma as a disease amenable to public health interventions has most notably been successfully implemented in Scotland where specialist police Violence Reduction Units led to a 69% decrease in incidents of handling an offensive weapon and a drastic drop in teenage murders over a 10-year period (3,4).

A further shift in recent years has been towards recognising the growing impact of an ageing population on trauma presentations and management. This is most notable in the developed world which has an older age demographic. A 2018 US study of over a million blunt trauma patient admissions showed an age of 60 and above to be an independent predictor of mortality (5).

1.2 Trauma Systems

1.2.1 A Brief History

A trauma system is the amalgamation of several organised processes for delivering appropriate levels of care to injured patients within a given geographical area. There are pre-hospital, in-hospital and post-discharge components of the system thus requiring trauma systems to be embedded within the regional public health system. The basic premise is that patients are taken directly to the hospital best suited to their needs within their geographical region rather than simply their nearest hospital. For seriously injured patients this means direct transfer to a specialist trauma centre with 24 hour on-site senior emergency surgical and critical care expertise required to manage these patients(6). The following sections will detail the structure of trauma systems and discuss the London Major Trauma System in further detail.

As with many aspects of trauma care and innovation, the origins of trauma systems can be traced back to the military. On the battlefields of the American Civil War in the 1860s the emphasis on the rapid treatment of injured soldiers dictated the organisation of medical staff, transport crews, and field hospitals(7). In the First World War, rapid evacuation of injured troops through echelons of increasingly capable treatment facilities became normal protocol. In the Second World War soldiers' passage through echelons of care became quicker and blood-product resuscitation and surgical intervention was more effective, all of which contributed to improved survival for seriously wounded soldiers. In World War I, the time interval from injury to treatment averaged 12 to 18 hours, but motorised transport in World War II reduced this time by 50% (8). The Korean War of the early 1950s saw the use of helicopters to deliver wounded soldiers directly to mobile army surgical hospitals located near the front lines, and the Vietnam War of the late 1960s saw further refinements of field transport systems (9).

In the civilian realm, a 1966 National Academy of Sciences report detailed the state of initial care and emergency medical services afforded to victims of accidental injury in the United States (10). A number of wide-ranging recommendations were made including the development of national courses in first aid and emergency care for all emergency services personnel, establishment of pilot programs to evaluate physician-staffed ambulances and helicopter ambulance services and the introduction of a single nationwide emergency telephone number. Specific to trauma the study committee advocated for the development of trauma registries, formation of hospital trauma committees and the development of a system of continual categorisation and accreditation of emergency departments. Their initial proposal was for emergency departments to be categorised in a stepwise fashion as advanced first aid facilities, limited emergency facilities, major emergency facilities and finally emergency facilities combined with a trauma research unit.

A landmark study in the late 1970s by West et al examined the rate of preventable deaths following road traffic collisions in Orange County and San Francisco (11). In Orange County the patients had been taken by ambulance to the nearest emergency department and out of 90 cases approximately two-thirds of non-CNS-related deaths and one third of CNS-related deaths were deemed to be preventable following autopsy. By contrast, of the 92 cases that had been brought to a single specialised trauma centre in San Francisco only a single death was deemed to have been preventable. This was despite the fact that Orange Country patients had a lower average Injury Severity Score (see Chapter 2.5.5) than the San Francisco patients. This led the authors to conclude that survival rates for major trauma could be improved by organised systems of trauma care involving the specialist resources of a trauma centre. In June 1980 a trauma system was set-up in Orange County and a follow-up study led by the same author showed a significant reduction in preventable deaths with only 9% of deaths at the newly-designated trauma centre deemed to be preventable (12).

1.2.2 The Case for Trauma Systems

With the establishment of further regional trauma systems throughout the 1980s and 1990s aided by increased federal funding, there was increasing evidence demonstrating improvements in trauma patient outcomes. In 1999 Mullins et al published a systematic review of population-based studies comparing trauma system outcomes with those of control populations not served by trauma centres. They showed a 15-20% improvement in survival rates among seriously injured patients managed within trauma systems (13). In 2006 Mackenzie et al published findings from a multi-institutional prospective study comparing mortality at specialist trauma centres with non-trauma centres (14). This study of over 5000 adult trauma patients at 18 trauma centres and 51 non-trauma centres across 14 states showed a 20% risk reduction for in-hospital mortalities and 25% risk reduction for 1 year mortality in patients treated at trauma centres. The mortality benefit was confined to patients with more severe injuries. This study contained relatively few elderly patients with severe injuries which may have contributed to their inability to detect a significant interaction between type of hospital and age. Furthermore, only 67% of eligible trauma centres and 41% of non-trauma centres agreed to participate in the study, inevitably leading to a degree of selection bias with perhaps the highest performing trauma centres preferentially opting in.

In Australia, Cameron et al conducted a population-based cohort study of almost 7000 severely injured patients admitted to the Victoria State Trauma System from 2001 to 2006, which covered the phased introduction period of the new statewide system from 2000 to 2003. In the paper they demonstrated an almost 40% reduction in the risk-adjusted mortality of patients treated in the final year of the study when compared to the first year(15). Vali et al performed a systematic review of interventional studies where trauma regionalisation was the intervention. They reviewed 24 American, Canadian, British, Australian and Dutch trauma system studies with a meta-analysis on a small sub-set of just two studies showing an overall 16% mortality reduction following trauma system implementation (16). They commented on the lack of randomised studies and overall weakness of the available literature which precluded them from conducting a full meta-analysis on all the studies. An earlier systematic review and meta-analysis by Celso et al of 14 studies showed a similar 15% mortality reduction (17). In their case 6 of the 14 studies had gone forward for meta-analysis. Overall there is a significant amount of medical literature supporting the implementation of regional trauma systems as a means to improving morbidity and mortality outcomes among severely injured patients (17,18,27,19−26). The unifying issue is that these are often observational studies and retrospective cohort studies utilising varying qualities of trauma registry data. As such they are often inferior levels of evidence compared to prospective studies and are subject to information bias in terms of the quality of data collected. Selection bias may be evident in terms of hospital sites willing to participate and the non-standardisation of trauma care between hospitals even within the same trauma system. It can also be difficult to account for confounding variables and causation cannot be determined.

The bulk of previous work analysing the impact of trauma systems has come from US studies. Lessons drawn from these may not be fully applicable to UK systems as not only are the systems and governance structures themselves more mature, but the research settings differ in terms of geography (i.e. prolonged prehospital times, especially in rural settings), prehospital Emergency Medical Service (EMS) capabilities and the impact that differing socioeconomic statuses and insurance cover may have on patients longer term care. There remains a need for further UK-based high-quality research.

Trauma systems can broadly be divided into inclusive or exclusive systems (28). Early trauma systems tended to be exclusive in that all trauma patients in the region, irrespective of injury severity were taken to a single trauma centre for definitive care. Modern trauma systems are inclusive meaning that all the acute hospital within a region are designated as trauma-receiving hospitals and will be expected to deliver care to patients with a level of injury severity that matches the resources and expertise they can provide. In the UK there are 2 levels of care:

- Major Trauma Centres (MTCs) which have the multidisciplinary resources to manage the most severely injured polytrauma patients 24 hours a day, 7 days a week from anywhere within the region of the trauma network.

- Trauma Units (TUs) which are responsible for the local management of less severely injured patients in their immediate catchment areas. Secondary transfer protocols allow for the rapid transfer of patients from TUs to MTCs as their clinical needs change.

An MTC is more than simply a large teaching hospital with all the relevant specialties on-site (i.e. neurosurgery, orthopaedics, vascular, cardiothoracic etc) as Davenport et al (29) demonstrated in their comparative analysis of data from the Royal London Hospital (RLH) from 2000 to 2005, a period which preceded the setup of the London Major Trauma System. In this study they detail the formation of their multidisciplinary trauma service in 2003 which took overall responsibility for all trauma patients. A dedicated trauma ward was opened, and a formal performance improvement programme was instituted to review the process of care for all deaths and serious morbidities, and to quality assure the development and implementation of management guidelines. They also established secondary transfer protocols with local surrounding hospitals. Mortality rates fell by 48% from 2000 to 2005 at the RLH whilst remaining unchanged over the same period at other large multi-specialty and acute hospitals around the UK. One of the key limitations of the study was that at the time of publication, TARN data was only available for 48% of acute hospitals meaning any comparisons made with the performance of other UK hospitals would have been limited in scope. Nonetheless, there was a sharp decrease in RLH mortality rate associated with institution of the multidisciplinary trauma service in 2003.

In North America there are several more tiers of trauma centre designation (Levels I to V). A British MTC would be equivalent to an American Level I or II trauma centre whereas a TU would be equivalent to Level III or below. In an inclusive system all levels of trauma centre designation play a role in the treatment of all trauma patients, hence the concept of getting the right patient to the right place first time.

A number of studies have compared inclusive and exclusive designs and concluded that greater inclusivity improves mortality outcomes. Utter et al performed a retrospective cohort study of 14 state-wide trauma systems and grouped levels of system inclusivity according to the percentage of hospitals with trauma centre designation (Levels I to V) (30). Regions with the highest numbers of trauma centres (38-100%) were deemed the most inclusive and were shown to have a 23% adjusted mortality reduction compared to the most exclusive systems (0 -13% hospitals designated Level I to V). Patients within more inclusive systems were no more likely to be admitted to Level I or II centres suggesting a more even distribution of workload across the system. This study was limited by its retrospective nature and drew data from still maturing systems around the USA. A further systematic review and meta-analysis by Moore et al identified helicopter transport and inclusive design as the two components of a trauma system most associated with mortality reduction with the latter resulting in 28% reduced mortality (24).

Greater inclusivity of trauma systems is to be encouraged not simply due to the mortality benefits but because it may also reduce pressure at the major trauma centres within each network thus improving efficiency of the system as a whole and improving the experience for patients and their families (31). There are important benefits in patients being managed in their local unit if specialist MTC/Level I services are not required. Patients are closer to their social support networks, and it may be easier to access local community services for discharge planning. This may be especially important in the elderly. Maintaining adequate and appropriate trauma volumes is also important for clinical effectiveness and training at all levels of a trauma system. Whether a patient is admitted to an MTC or a TU depends primarily on how the emergency services triage the patient in the prehospital phase. Trauma triage is explored in greater detail in 1.2.4 below, but there is clearly a close co-dependency between the effective quality of care across an inclusive major trauma system and its prehospital triage protocols. Understanding where patients receive the most effective care and optimising resource utilisation is at the heart of trauma system governance and development.

1.2.3 Trauma Registries

As trauma care has evolved and become more organised over the years there has been a greater need for better integration of trauma care into the larger public health framework. Treating trauma as a disease and adopting a public health approach involves identifying the problem, designing preventative and interventional strategies to tackle it and re-evaluating the impact of implemented interventions (32). Continued research and development is required in all aspects of the trauma continuum from injury prevention and ambulance dispatch and treatment protocols through to in-patient care and rehabilitation provision. Underpinning all of this are trauma registries.

The American College of Surgeons Committee on Trauma defines a trauma registry as '*a disease-specific data collection composed of a file of uniform data elements that describe the injury event, demographics, prehospital information, diagnosis, care, outcomes, and costs of treatment of injured patients.*'(32). Trauma registries in the United States are maintained at state as well as national level (National Trauma Data Bank). In England and Wales the Trauma Audit and Research Network (TARN) serve as the official trauma registry (see Chapter 2.3.1)

1.2.4 Trauma Triage

Prehospital or field triage is the initial step in the activation of a trauma system. All injured patients are assessed at scene using a standardised triage tool to determine the level of trauma care required for their condition. Triage tools are step-wise hierarchical algorithms that enable prehospital care providers to use the real-time information available to them to make a decision on patient destination. Furthermore, activation of triage tools enables prehospital teams to pre-alert receiving hospitals, enabling them to assemble the required treatment teams prior to patient arrival. Triage tools are tailored to individual trauma systems to take into account each region’s unique geographical and logistical considerations. Most modern triage tools derive their structure from the American College of Surgeons Field Triage Decision Scheme (Fig 1.1) which was based off work done on prehospital triage in the 1970s and 1980s (33).

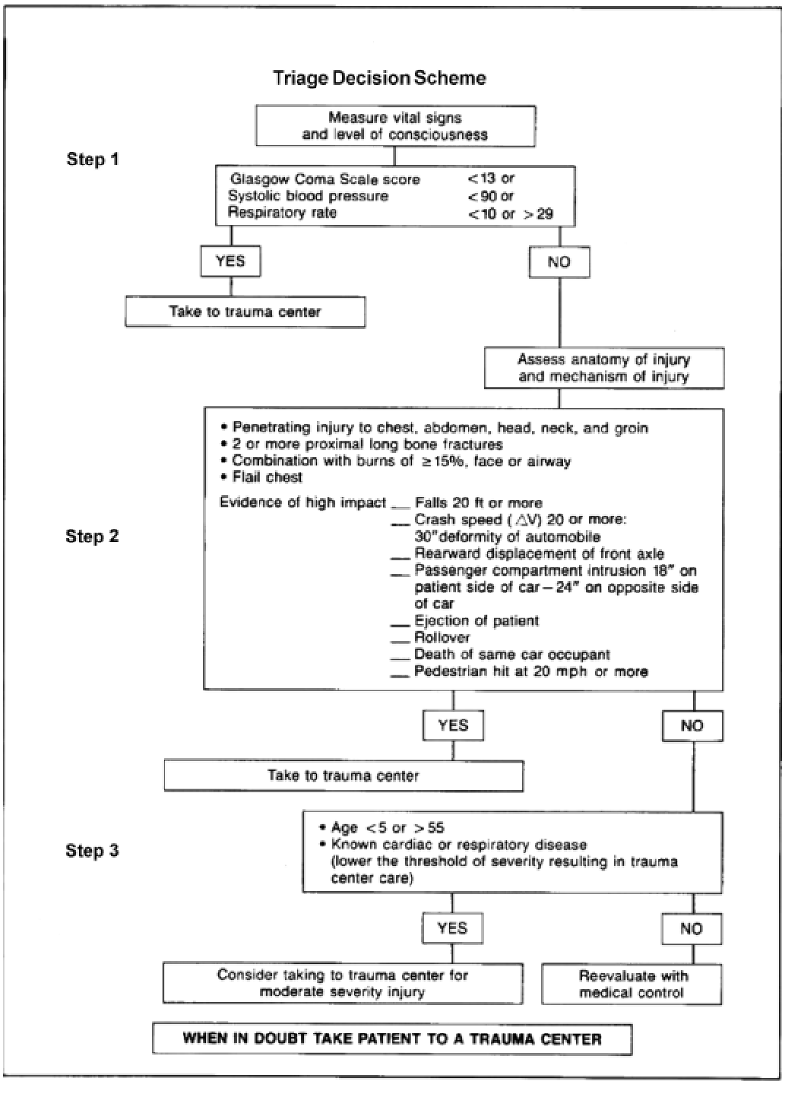


Figure 1.1: American College of Surgeons Field triage decision protocol (Hospital and Prehospital Resources for the Optimal Care of the Injured Patient. Chicago, IL American College of Surgeons, 1987)

Physiological derangement (neurological, cardiovascular and/or respiratory function) is the first element to be assessed. This is followed by anatomical injury and then injury mechanism. Patients may trigger direct transport to a trauma centre based on positive findings in any of these realms. The London Triage Tool is introduced in Chapter 2.2. and forms the basis of this thesis.

The accuracy of triage tool has long been a source of debate (34) with tools having to balance the implications of overtriage and undertriage. Overtriage occurs when patients without severe injury requiring specialist care are taken to high level trauma centres whereas undertriage occurs when severely injured patients in need of specialist trauma care are instead taken to non-trauma centres or low-level trauma centres. Undertriage has obvious immediate implications for patient safety resulting in increased morbidity and mortality and poorer functional outcomes (14,26,35). Overtriage is associated with increased workload at high-level trauma centres with the associated cost implications (36,37). For obvious reasons most prehospital triage tools are designed to minimise under-triage with wide activation criteria to maximise the sensitivity of the triage process (38). However, this necessarily results in reduced tool specificity and large numbers of overtriaged patients who do not require specialist major trauma care. Aside from the resource implications to the high-level trauma centres, these patients may end up being transferred far from home and may suffer delays in care due to their relatively low priority at high-level centres.

The Cribari matrix has traditionally been the formula used for calculating undertriage and overtriage rates in the USA (32). It was developed by Chris Cribari, a previous chair of the Verification Review Subcommittee of the American College of Surgeons (ACS) Committee on Trauma and is often utilised as a screening tool for potentially over or under-triaged patients whose medical records may need further review. Using a simple 2x2 contingency table format, triage sensitivity and specificity can be determined using the patients Injury Severity Score (ISS) (see Chapter 2.5.5) and whether a full trauma team was activated for the patient (Table 1.1). AN ISS of greater than 15 represents major trauma. It is important to acknowledge that this method for calculating under/overtriage centres on the appropriateness of trauma team activation within a given hospital and not whether a patient was taken to the appropriate level of trauma centre. Calculation of under/overtriage within inclusive systems will often substitute ‘Trauma Team Activation’ for ‘MTC (or equivalent)’ and ‘no Trauma Team Activation’ for ‘TU (or equivalent)’.

	Minor Trauma (ISS<15)	**Major Trauma (ISS>15)**	**Total**
Full Trauma Team Activation (MTC admission)	a (FP)	b (TP)	a+b
Limited/No Trauma Team Activation (TU admission)	c (TN)	d (FN)	c+d
Total	a+c	b+d	

Table 1.1: Modified Cribari Matrix for calculation of under-triage and over-triage

FP= false positive TP= true positive TN= true negative FN= false negative
Over-triage rate = a/(a+b); Under-triage rate= d/(c+d)

The ACS Committee on Trauma advocates allowing for an under-triage rate of below 5% with over-triage rates of 25-35% also seen as acceptable (32). A further method of measuring undertriage acknowledged by the ACS is to identify all the potentially preventable deaths that occur within a regionalised trauma system. Undertriaged patients would be those who were taken to a non–trauma centre/TU-equivalent hospital and then died of potentially preventable causes. By using this method, a target under-triage rate would be 1% or less.

Pre-hospital under-triage may be tolerated where all hospitals that receive injured patients are also designated as trauma centres (regardless of level) and incorporated into an inclusive trauma system. Exclusive systems that only recognise MTC-level centres may improve outcomes at these select few centres but are associated with increased preventable death rates when patients present to other non-trauma hospitals in the region (39). Provided there is effective immediate diagnosis and pathways for rapid onward transfer, secondary transfers to an MTC following initial assessment and treatment at a TU-level facility may be safe for all but the most time-critical patient. In this 'error tolerant' context, prehospital triage tools may not need to be so sensitive and therefore may be modified for inclusive trauma systems.

1.2.5 The UK Experience

The topic of improving the care of trauma patients didn't gain much traction in the UK until the late 1980s. In 1988 The Royal College of Surgeons of England issued a report documenting cases of patients dying unnecessarily because of the delay in appropriate medical care (40). The same year Anderson et al published a review of 1000 consecutive trauma deaths in England and Wales and found up to a third to had been preventable (41). Preventable deaths were principally due to failure to control haemorrhage or prevent hypoxia and delays to surgery. A 1992 publication from the Major Trauma Outcomes Study (MTOS) reviewed the care of almost 15,000 patients across 33 hospitals over two years (42). It found that over 20% of patients took more than 1 hour to get to hospital and fewer than 50% of patients deemed to need urgent surgery were actually in theatre within 2 hours. It also showed higher trauma mortality rates at larger UK hospital compared to their US trauma centre counterparts, more junior staff members leading the care of trauma patients and large interhospital variation in mortality outcomes. In 2000 a joint report by the Royal College of Surgeons of England and the British Orthopaedic Association made a number of recommendations in a push for a nationally co-ordinated and systematically audited standard of trauma care (43). It called for geographical trauma systems to be set up and made other recommendations on areas such as trauma rehabilitation and intensive care provision. MTOS, coordinated through the University of Manchester continued to collect data throughout the early to mid 1990s, by which point the Department for Health were keen for continuous trauma audit to become an integral part of hospital activity (44). MTOS became the Trauma Audit and Research Network which serves as the trauma registry for England and Wales (Chapter 1.2.3 and 2.4.1)

The landmark 2007 report of the National Confidential Enquiry into Patient Outcome and Death (NCEPOD) examined processes of care at all stages of a trauma patient's journey, from prehospital to rehabilitation and concluded that 60% of patients received a standard of care that was less than good and identified deficiencies in both the organisational clinical aspects of care (45). . Three years later in April 2010, the Greater London urban area implemented the UK's first regionalised trauma system and at the same time became the first region in the world to implement a trauma system for a population of 10 million people. Since then regional trauma systems have been establish all over the country.

Established patient pathways involve the direct admission of patients who trigger any aspect of the triage tool (triage-positive) to an MTC, bypassing all other hospitals that may be geographically closer to the scene of injury (primary bypass). Patients who do not trigger the tool (triage-negative) are admitted to the nearest TU. Patients who have been found to have been under-triaged or who deteriorate or develop problems beyond the capabilities of the TU may undergo secondary transfer to MTCs. This may happen within minutes, hours or days of arrival at the TU. Patients treated at MTCs may be discharge from there or repatriated to their local MTC for ongoing inpatient therapies and rehabilitation which do not require the specialist resources of an MTC. It is also important to acknowledge that MTCs function as TUs for patients injured in their local catchment area, so triage-negative patients close to an MTC will also be admitted there (Fig 1.2).

The quality and processes of care within the London Trauma System were evaluated 3 years after it's inception using the same NCEPOD methodology. The Evaluation of the London Trauma System (ELoTS) showed that overall quality of care had significantly improved as a result of regionalisation (46). These improvements were mainly achieved through better organisational processes such as increased utilisation of helicopter emergency services, senior doctors available earlier to expedite decision making, quicker diagnostic imaging and timely urgent operations. Improved processes of care were associated with improved survival, where in NCEPOD 18% of patients died, compared to 7% in ELoTS.

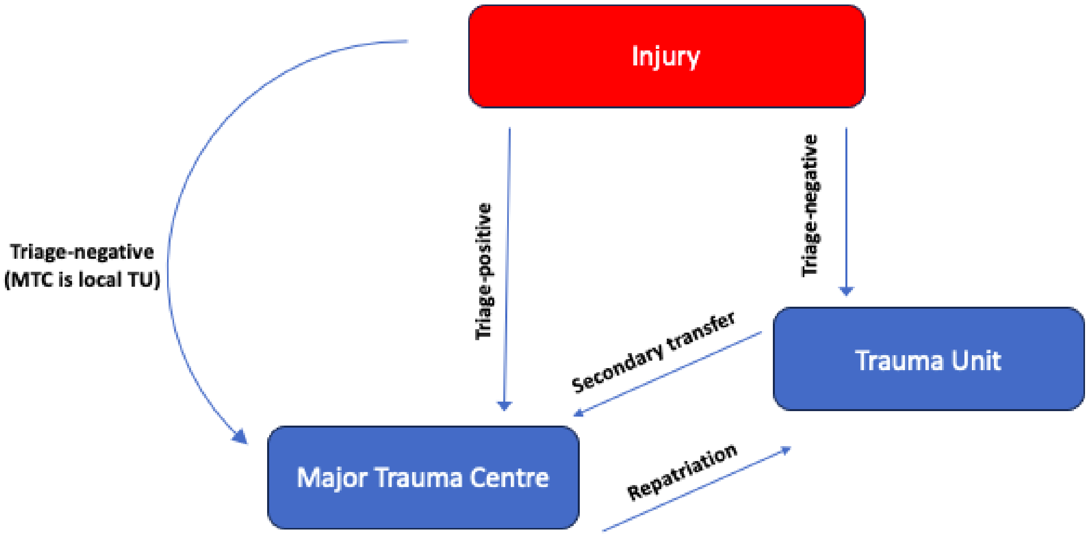


Figure 1.2: Schematic of patient pathways within the London Major Trauma System

1.2.6 The London Major Trauma System

This research is centred around the pan-London Major Trauma System (LMTS). The LMTS was implemented in April 2010 and serves a population of over 10 million people. At its inception it was the first regional trauma system in the UK. This inclusive system comprises 4 individual networks covering the North East, North West, South East and South West regions of the Greater London area and parts of the neighbouring home counties (Essex, Hertfordshire, Kent and Surrey respectively) (Fig. 1.3). Each network is led by a Major Trauma Centre (equivalent to a Level I or II trauma centre in North America) which has the resources to manage the most severely injured polytrauma patients 24 hours a day, 7 days a week. Major Trauma Centres (MTCs) are supported within their networks by a number of hospitals designated as Trauma Units (equivalent to Level III trauma centre and below) which are responsible for the local management of less severely injured patients. There are currently 35 Trauma Units (TUs) in total. Well-established transfer protocols exist to allow for the rapid movement of patients from TUs to MTCs should the severity or complexity of injury exceed the capabilities of the TU. Equally, patients may undergo their initial emergency treatment at the regional MTC before being repatriated to their local TU for ongoing supportive care or rehabilitation closer to home. MTCs also provide clinical governance and educational oversight for the TUs within their networks.

According to TARN registry data (see Chapter 2.3.1) for the 2020 calendar year there were 15002 trauma admissions to hospitals within the LMTS. These would mostly have been patients who stayed in hospital for at least 3 days following admissions for a traumatic injury (see 2.3.1 for full TARN inclusion criteria). Just 482 (3%) of admissions were minors (aged under 16) and 7546 (5%) of patients were 70 years or older. Penetrating trauma accounted for 3% of injury mechanisms across the whole group, although in the 16-25 year age group this rose to 21%. In the adult population (age 16 and over) a total of 2178 patients activated the London trauma triage tool to justify direct admission to an MTC (triage positive); although in total there were 4726 primary MTC admissions. Among adult MTC admissions 1818 patients (38%) were triage positive although triage status was not recorded for almost half of patients. A number of patients will have been admitted to MTCs as this would have been their local hospital regardless of injury severity (Fig. 1.2).

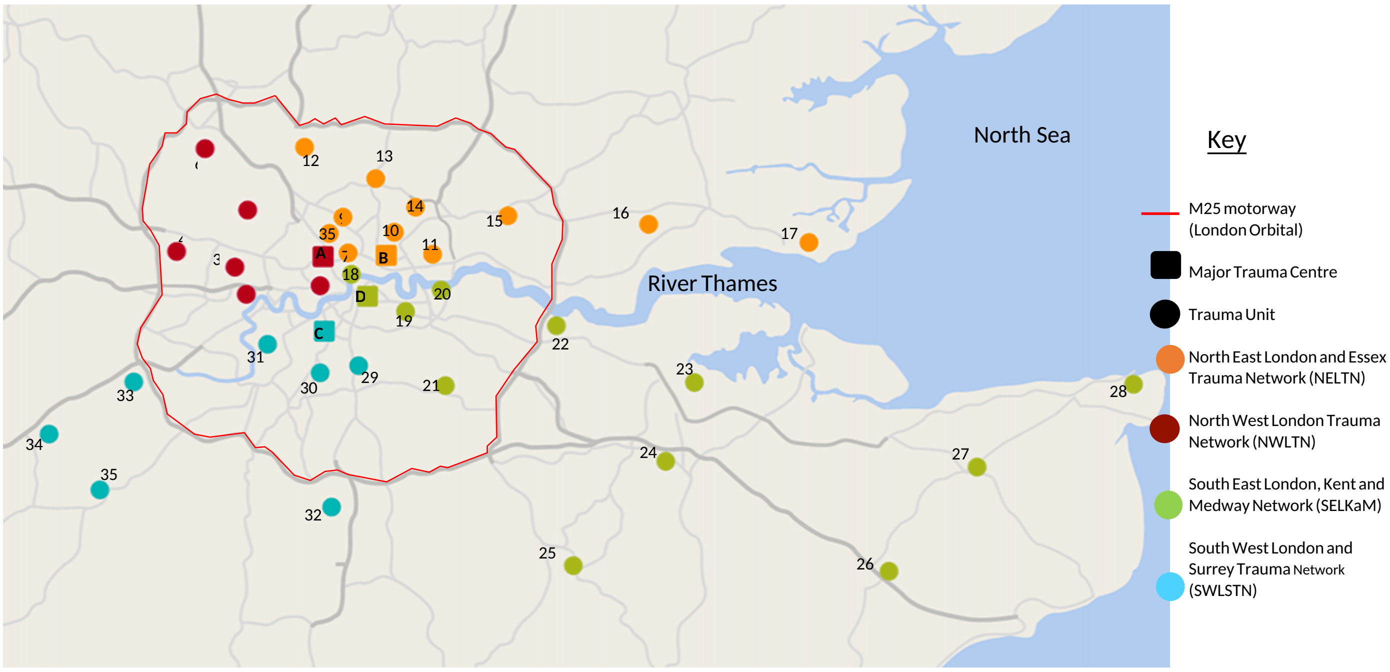


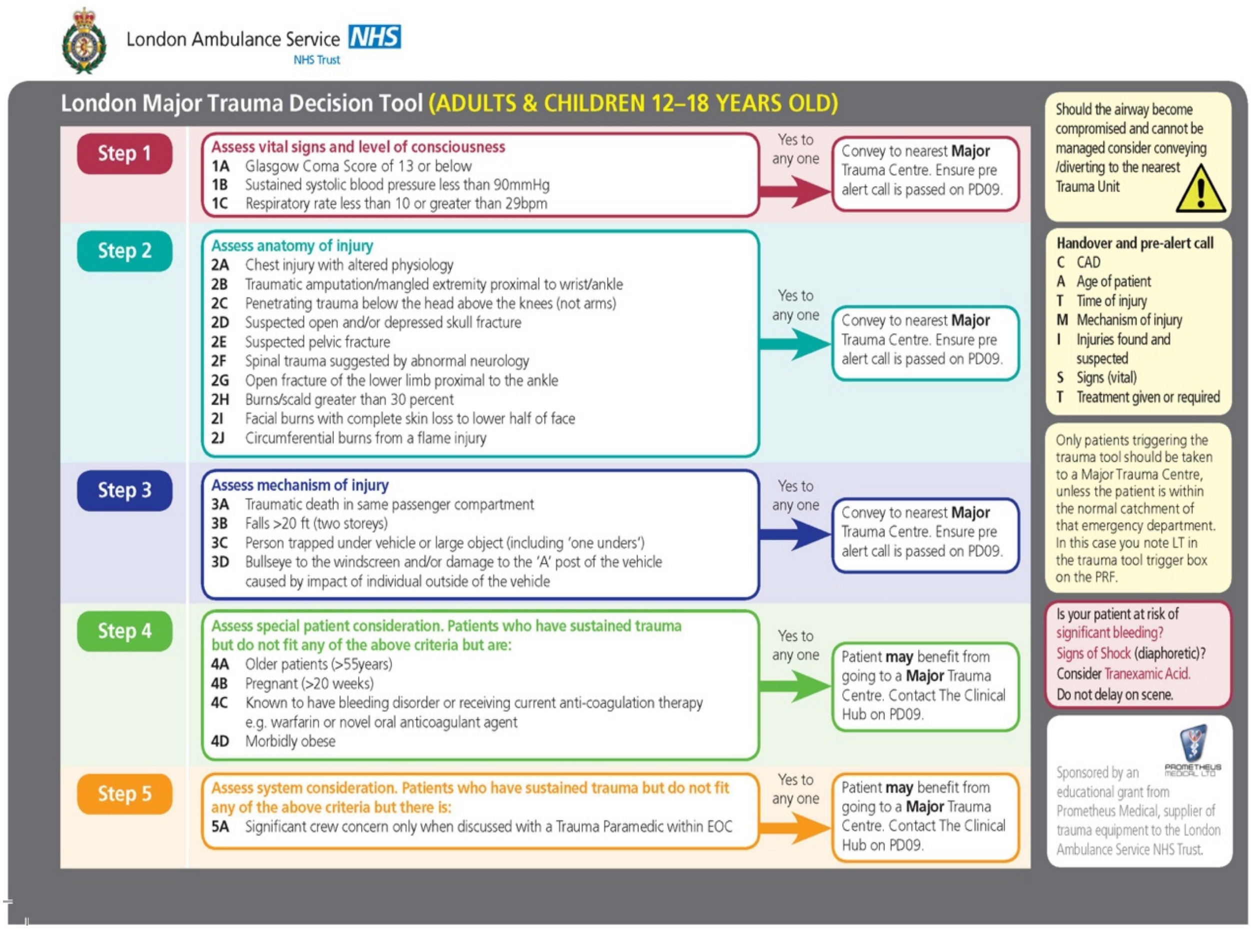
Figure 1.3: London Major Trauma System (adapted from Centre for Trauma Sciences)

A: St Mary's Hospital, B: Royal London Hospital, C: St George's Hospital, D: Kings College Hospital*, 1: Chelsea & Westminster Hospital, 2: West Middlesex Hospital, 3: Ealing Hospital, 4: Hillingdon Hospital, 5: Northwick Park Hospital, 6: Watford General Hospital, 7: University College Hospital, 8: Royal Free Hospital, 9: Whittington Hospital, 10: Homerton University Hospital, 11: Newham University Hospital, 12: Barnet Hospital, 13: North Middlesex Hospital, 14: Whipps Cross Hospital, 15: Queens Hospital, 16: Basildon University Hospital, 17: Southend University Hospital, 18: St Thomas' Hospital, 19: University Hospital Lewisham, 20: Queen Elizabeth Hospital, 21: Princess Royal University Hospital, 22: Darent Valley University Hospital, 23: Medway Maritime Hospital, 24: Maidstone Hospital, 25: Tunbridge Wells Hospital, 26: William Harvey Hospital, 27: Kent and Canterbury Hospital, 28: Queen Elizabeth Queen Mother Hospital, 29: Croydon University Hospital, 30: St Helier Hospital, 31: Kingston Hospital, 32: East Surrey Hospital, 33: St Peter's Hospital, 34: Frimley Park Hospital, 35: Royal Surrey County Hospital*

Prehospital care within the LMTS is largely provided by the London Ambulance Service, although surrounding ambulance services such as East of England and South East Coast Ambulance Service regularly transport patients to hospitals within the LMTS from the aforementioned neighbouring counties. The system is also served by physician-led Helicopter Emergency Medical Services (HEMS) from the London Air Ambulance (LAA), Essex & Herts Air Ambulance and Kent, Surrey & Sussex Air Ambulances. HEMS teams from further afield may also convey patients into the system depending upon mission location and mutual aid agreements. HEMS operations are aided by the fact that (at the time of writing) three of the four London MTCs now have dedicated helipads on-site, with the operational base of LAA being the Royal London Hospital. HEMS teams can provide advanced trauma care at scene including the delivery of emergency anaesthesia, advanced airway management, resuscitative thoracotomy and aortic occlusion procedures.

The initial hospital destination of patients within the LMTS is determined by whether the patients trigger specific triage criteria detailed on the London Major Trauma Decision Tool (Fig. 1.4). This triage tool (referred to throughout this thesis as simply the London Triage Tool) is based on American-designed triage tools as set out by the American College of Surgeons and the Centers for Disease Control and Prevention National Field Triage Guidelines (47). It is a step-wise hierarchical algorithm used to identify patients requiring the specialist trauma care services of an MTC. It requires the prehospital care provider to assess first physiological derangement, followed by the anatomical aspects of injury, followed by injury mechanism and then other special considerations which warrant a higher level of care. There is also a provision for ambulance crews to take patients to MTCs based on clinical concerns not otherwise specified on the triage tool. Each 'Step' on the tool (physiology, anatomy, mechanism, special concerns) is further broken down into the specific 'triggers' qualifying the patient for MTC admission. Patients who trigger any aspect of the triage tool are said to be 'triage-positive' and are conveyed directly to MTCs, bypassing any TUs which may be geographically closer to the scene of incident. For example, a triage-positive patient in Southend would make the near 40-mile journey to The Royal London Hospital, bypassing Basildon, Queens and any other TUs or hospitals along the way. The tool presented in Fig. 1.4. was the tool in use by the London Ambulance Service at the time of commencing this research project. The tool was changed in March 2020 following findings detailed in this thesis (also see Chapter 6.7 and Appendix 4).

Trauma patients who do not trigger the triage tool (triage-negative) are taken to the nearest TU, with protocols in place to facilitate urgent ambulance transfer to the regional MTC should that patient deteriorate or it becomes apparent that their clinical needs exceed the capabilities of the TU. Patients who do not trigger criteria for direct admission to an MTC may still be taken to an MTC if they are within the normal catchment area of that emergency department. For example, a patient sustaining a minor injury in Paddington would still be taken to St Mary's Hospital as this would be their local emergency department irrespective of trauma system protocols. The tool may also be overruled by HEMS physicians.



London Ambulance Service NHS
NHS Trust

London Major Trauma Decision Tool (ADULTS & CHILDREN 12–18 YEARS OLD)

Step 1

Assess vital signs and level of consciousness

- **1A** Glasgow Coma Score of 13 or below
- **1B** Sustained systolic blood pressure less than 90mmHg
- **1C** Respiratory rate less than 10 or greater than 29bpm

Yes to any one → Convey to nearest **Major** Trauma Centre. Ensure pre alert call is passed on PD09.

Step 2

Assess anatomy of injury

- **2A** Chest injury with altered physiology
- **2B** Traumatic amputation/mangled extremity proximal to wrist/ankle
- **2C** Penetrating trauma below the head above the knees (not arms)
- **2D** Suspected open and/or depressed skull fracture
- **2E** Suspected pelvic fracture
- **2F** Spinal trauma suggested by abnormal neurology
- **2G** Open fracture of the lower limb proximal to the ankle
- **2H** Burns/scald greater than 30 percent
- **2I** Facial burns with complete skin loss to lower half of face
- **2J** Circumferential burns from a flame injury

Yes to any one → Convey to nearest **Major** Trauma Centre. Ensure pre alert call is passed on PD09.

Step 3

Assess mechanism of injury

- **3A** Traumatic death in same passenger compartment
- **3B** Falls >20 ft (two storeys)
- **3C** Person trapped under vehicle or large object (including 'one unders')
- **3D** Bullseye to the windscreen and/or damage to the 'A' post of the vehicle caused by impact of individual outside of the vehicle

Yes to any one → Convey to nearest **Major** Trauma Centre. Ensure pre alert call is passed on PD09.

Step 4

Assess special patient consideration. Patients who have sustained trauma but do not fit any of the above criteria but are:

- **4A** Older patients (>55years)
- **4B** Pregnant (>20 weeks)
- **4C** Known to have bleeding disorder or receiving current anti-coagulation therapy e.g. warfarin or novel oral anticoagulant agent
- **4D** Morbidly obese

Yes to any one → Patient **may** benefit from going to a **Major** Trauma Centre. Contact The Clinical Hub on PD09.

Step 5

Assess system consideration. Patients who have sustained trauma but do not fit any of the above criteria but there is:

- **5A** Significant crew concern only when discussed with a Trauma Paramedic within EOC

Yes to any one → Patient **may** benefit from going to a **Major** Trauma Centre. Contact The Clinical Hub on PD09.

Should the airway become compromised and cannot be managed consider conveying /diverting to the nearest Trauma Unit ⚠

Handover and pre-alert call
- **C** CAD
- **A** Age of patient
- **T** Time of injury
- **M** Mechanism of injury
- **I** Injuries found and suspected
- **S** Signs (vital)
- **T** Treatment given or required

Only patients triggering the trauma tool should be taken to a Major Trauma Centre, unless the patient is within the normal catchment of that emergency department. In this case you note LT in the trauma tool trigger box on the PRF.

Is your patient at risk of significant bleeding? Signs of Shock (diaphoretic)? Consider Tranexamic Acid. Do not delay on scene.

PROMETHEUS MEDICAL LTD

Sponsored by an educational grant from Prometheus Medical, supplier of trauma equipment to the London Ambulance Service NHS Trust.

Figure 1.4: London Major Trauma Decision Tool (at the time of commencing this research in 2017)

With trauma systems in place nationwide efforts continue to refine their performance and ensure good quality care is provided for all patients. This includes the non-trauma patients at designated MTCs who may have their own care adversely affected by the trauma-related clinical workload and demand on finite hospital resources. It remains unclear which cohort of patients benefit from direct MTC admission and which patients are not harmed by initial triage to a TU followed by secondary transfer to an MTC if later if deemed necessary. Furthermore, with an increasingly ageing population, and with old age known to be a risk factor for worse outcomes in trauma patients, it is important to ensure appropriate age cut-offs are factored into trauma triage. Elderly patients with their differing physiological presentations and injury mechanisms present a unique challenge to the optimisation of trauma triage.

By identifying more patients who may safely be taken to their local TU for non-specialist treatment it may be possible to free up MTC resources and improve patient satisfaction overall by keeping people in their local communities where they may have their social support networks. Individual study aims and objectives are discussed in the following chapter an in each research chapter, but the key principle of this research was the optimisation of the existing triage protocols to better serve all stakeholders.

The approach adopted in this research was to begin with a subset of the overall trauma population and identify potential opportunities for improvement that might be extrapolated to the wider trauma patient population. Traumatic brain injury (TBI) was felt to be a suitable area to commence with. TBI is the dominant cause of mortality and disability after injury (48,49). As an isolated injury pattern it has the potential to have a disproportionate impact on the quality of life of patients and their loved ones. Not all TBI requires neurosurgery or specialist neurocritical intervention which is normally only available at MTCs. Many patients may be managed conservatively with close observation and serial cross-sectional imaging. TBI therefore offered a useful opportunity to study the impact of differing care settings on its management and how outcomes differed. From there the triage tool is examined in its entirety in the Trauma Triage and Outcomes Research (TuTOR) study (Chapter 4) and potential areas for improvement are highlighted (Chapter 5).

Chapter 2: Methods

2.1 Aims and Objectives

Several separate studies comprise this overall body if work. In this section the overall aims and study design for each one are outlined:

2.1.1 STUDY 1: Triage in Traumatic Brain Injury: Not simply a case of 'Right Place, First Time'

The overall aim of the study was to determine the outcomes of patients with isolated moderate and severe traumatic brain injury (TBI) managed across an inclusive trauma system. For patients requiring neurospecialist care (including neurosurgical intervention), the objective was to determine whether outcomes were different depending on the initial level of trauma centre that the patient was admitted to. A secondary objective was to investigate outcomes across the system for patients who did not require neuro-specialist intervention for TBI.

This was a retrospective cohort study was conducted to include all adult patients with moderate and severe isolated TBI managed across the London Major Trauma System (LMTS) over a 3-year period.

2.1.2 STUDY 2: Defining the link between prehospital triage and outcomes

The overall aim of this study was to explore the relationship between prehospital triage decisions and patient outcomes in the context of an urban inclusive trauma system. Specific objectives were to identify which aspects of the London trauma triage tool best identify patients with traumatic injuries which required urgent surgical/radiological interventions. Specific objectives were to explore the relationship between prehospital trauma triage decisions, mortality, and discharge outcomes at major trauma centres. Additionally, I wished to specifically assess the performance of the existing age cut-off for direct triage to MTC (age >55 years).

A retrospective study was conducted of all trauma patients activating the existing London triage tool within a 12-month period across this urban inclusive trauma system.

2.1.3 STUDY 3: Modelling Changes to the London Triage Tool

The overall aim of this study was to use the dataset and recommendations from Study 2 to develop a computerised simulation model to examine the potential resource implications of implementing the TuTOR recommendations in the London Trauma System, with particular emphasis on MTC admissions and secondary transfer requirements placed on the London Ambulance Service

2.2 Research Approvals and Ethics

The research setting for all of the studies in this body of research was the London Major Trauma System. The research undertaken in Chapter 3 (Study 1: Triage in Traumatic Brain Injury) was a retrospective study using de-identified TARN registry data and as such did not require NHS Health Research Authority (HRA) approval according to the online HRA decision tool(50). The work undertaken for Chapters 4 (Study 2: London Triage Tool) and which subsequently fed into Chapter 5 (Study 3: Modelling changes in the London Triage Tool) stemmed from the Trauma Triage and Outcomes Research study (TuTOR). The TuTOR study required the use of patient identifiable data during the data collection phase and was therefore subject to HRA approval granted by the NHS Research Ethics Committee (REC). Whilst applying for HRA approval via the Integrated Research Application System (IRAS), a concurrent internal peer review process was undertaken to facilitate Queen Mary University acting as the study sponsor. All study co-investigators were required to produce proof of Good Clinical Practice training and the study protocol was scrutinised by an independent clinician with knowledge of the subject and the Clinical Trials Manager within the Centre for Trauma Sciences. HRA approval was formally granted on 27th November 2017 (REC reference 18/HRA/0399) and a Declaration of Sponsorship from Queen Mary University of London was received on 28th November 2017.

The TuTOR study involved the matching of TARN registry data with patient data from the internal LAS trauma registry. This data was only accessible on LAS computers and the data collection therefore had to conducted on LAS premises at the Clinical Audit Research Unit (CARU) at Pocock Street, London SE1. Authorised access to the building as well as IT log-in privileges were required. A Letter of Access was issued by LAS on 20/07/17 valid until 19/01/18 to enable a pilot database-matching study to be undertaken to check the feasibility of the TuTOR study. Upon receipt of HRA approval, LAS granted an extension of access for the research study valid to June 2018. The trials committee for TuTOR was as follows:

Chief Investigator: Dr Elaine Cole[1]
Co-principal investigators: Professor Karim Brohi[1], Dr Rachael Fothergill[2], Dr Heloise Mongue-Din[2]
Clinical Research Fellow: Mr Henry O Nnajiuba[1]
[1]Centre for Trauma Sciences, QMUL
[2]CARU, London Ambulance Service

2.3 Data Collection

The research in this thesis is built upon the use of prospectively collected trauma registry data from TARN. Patient data was received from TARN in the form of an Excel spreadsheet which required further cleaning prior to data analysis. A description of the data cleaning process and further background information on the UK's trauma registry are provided below (2.4.2).

2.3.1 Trauma Audit and Research Network (TARN)

The Trauma Audit and Research Network (TARN) maintains the trauma registry for England and Wales. TARN originated from the Major Trauma Outcomes Study which was involved in some of the early UK trauma research detailed in Chapter 1.2.5.

Patients are screened for TARN eligibility and their data uploaded to the registry by dedicated teams of administrators within each hospital. Data collected includes patient details, incident data, vital signs (prehospital and Emergency Department), imaging, operations (surgery), critical care admissions, outcomes and complications. Any trauma patient (as determined by an ‘S’ or ‘T’ ICD-10 code) of any age is eligible for TARN inclusion if they meet any of the following criteria:

- Stayed in hospital for 3 or more days
- Died in hospital (including in the Emergency Department)
- Admitted for critical care (Intensive Care or High-Dependency Care)
- Transferred in or out for specialist care or critical care admission

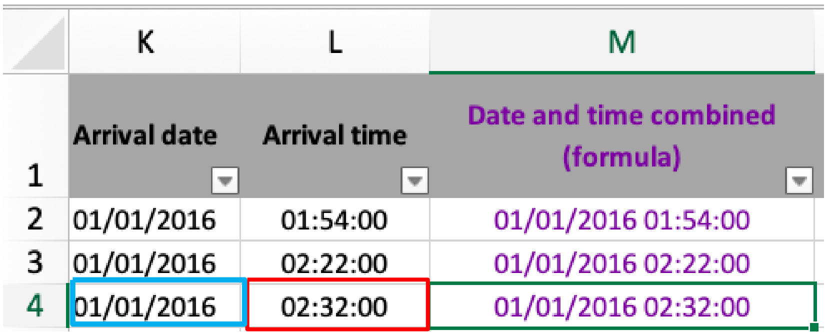
Data is uploaded on a continuous basis. Injury severity scores are calculated from AIS codes on discharge or death along with a probability of survival (PS), allowing for comparative outcome analyses between different hospitals and patient groups. Yearly performance data for individual hospitals is readily obtainable via the TARN website.

When requesting data from TARN an email request for the required patient variables was sent to the Executive Director. Detail on individual variables is provided in the relevant chapters.

2.3.2 Data Cleaning

De-identified patient data was received from TARN as a spreadsheet with each row representing a patient and each column representing a variable e.g. age on admission, gender etc. Filters were applied to the spreadsheet and patients under the age of 16 were excluded. Age was given in decimal format to one decimal point in the original spreadsheets sent from TARN. These were rounded up to whole numbers to prevent patients being missed out when age cohort filters were applied. Categorical variables were number coded (e.g. male=1, female=0) for subsequent regression analysis. Some continuous variables were dichotomised and treated as categorical data for analysis purposes (e.g. GCS<13: Yes=1, No=2). For all analysis of critical care lengths of stay, hospital lengths of stay and discharge destination non-survivors were excluded as in-hospital mortality represented an alternative adverse outcome irrespective of length of stay.

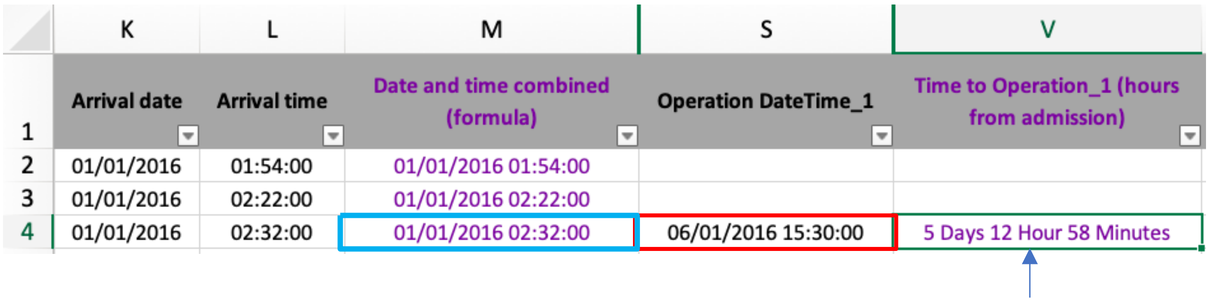
A required variable not routinely logged by TARN is ‘Time to Operation. Dates and times of admission and operation (surgery) are provided, however calculating the time difference between events had to be performed manually in Excel using formulae. This was a two-stage process first requiring the separate arrival date and arrival time columns to be merged into a single date-time column and secondly calculating the difference in hours and minutes between 2 date-time columns. Spreadsheet screenshots are provided in Figs. 2.1 and 2.2 illustrating the process and formulae involved.



	K	L	M
1	Arrival date	Arrival time	Date and time combined (formula)
2	01/01/2016	01:54:00	01/01/2016 01:54:00
3	01/01/2016	02:22:00	01/01/2016 02:22:00
4	01/01/2016	02:32:00	01/01/2016 02:32:00

=TEXT(K4,"dd/mm/yyyy")&" "&TEXT(L4,"hh:mm:ss")

Figure 2.1: Creating new date-time variables from separate date and time columns



	K	L	M	S	V
1	Arrival date	Arrival time	Date and time combined (formula)	Operation DateTime_1	Time to Operation_1 (hours from admission)
2	01/01/2016	01:54:00	01/01/2016 01:54:00		
3	01/01/2016	02:22:00	01/01/2016 02:22:00		
4	01/01/2016	02:32:00	01/01/2016 02:32:00	06/01/2016 15:30:00	5 Days 12 Hour 58 Minutes

=INT(S4-M4)&" Days "&HOUR(MOD(S4-M4,1))&" Hour "&MINUTE(MOD(S4-M4,1))&"

Figure 2.2: Calculating time difference between 2 date-time columns

2.3.3 Data Linkage

The London Trauma Triage study detailed in Chapter 4 was reliant upon the effective matching of patient records between 2 separate databases. These were the London Ambulance Service prehospital database and the TARN database.

Record linkage between different databases can be performed using either deterministic linkage or probabilistic linkage techniques. Deterministic linkage simply involves matching common identifiers between databases to determine that two records relate to the same patient. For example 'Patient A' from the LAS registry admitted to hospital on 5th October

2016 aged 18 with CAD 123 and 'Patient D' from the TARN registry admitted to hospital on 5th October 2016 with CAD 123 would be considered to be the same patient and therefore the triage data and outcome data from the respective databases would be linked.

Probabilistic linkage involves the calculation of linkage probabilities using multiple common identifiers which may not necessarily be identical between databases. It therefore better accommodates the inherent errors found in databases that rely upon manual data entry by clerical personnel. An overall linkage probability is calculated to determine the likelihood of a correct match. The underlying Fellegi-Sunter statistical method (51) relies upon the calculation of 2 weighted probabilities:

- Reliability/Match probability (m)- *The probability that 2 variables belonging to the same patient are actually entered correctly in the 2 databases and are therefore a true match*

- Discriminating Power/Un-match probability (u)- *The probability that 2 variables agree even though they are 2 different patients* (i.e. the probability of two unrelated patient records agreeing on admission month would be $^{1}/_{12}$ owing to there being 12 calendar months)

The log-transformed probabilities are given weight by multiplying them with the prior probabilities of achieving a match in each specific data field. Positive weights are applied to matched fields and negative weights to unmatched fields. The probabilities are assigned weights based upon the likelihood ratio of 2 variables agreeing by chance. For example, matching on a rare surname (e.g. Dankworth-Smithers) is unlikely to occur by chance and would therefore be assigned a higher weight than a match on a common surname (e.g. Smith). The sum of weighted probabilities from each field provides an overall linkage probability which is compared to a pre-defined threshold to determine whether 2 records do indeed belong to the same patient. The prior probabilities are calculated using Bayes theorem.

Newgard et al demonstrated probabilistic linkage to be a feasible way of accurately matching patients between a pre-hospital ambulance databases and state trauma registry, although the sensitivity for identifying true matches decreased for analyses with fewer than 15 variables (52). A study evaluating linkage methods in a simulated dataset found that probabilistic linkage was a more accurate method in poorer quality data with errors and missing values, although deterministic linkage was an equally valid and faster method in high quality data(53). Hagger-Johnson and colleagues applied probabilistic linkage techniques to a historic dataset of over 400,000 Hospital Episode Statistics (HES) data records which had previously been matched deterministically to link together multiple hospital admissions for the same patient. In doing so they reduced the non-match rate from 8.6% to 0.4% with clear implications for commissioning, service evaluation and performance monitoring of hospital readmission rates(54). Contrastingly, in a large US study evaluating the linkage of over 260,000 records on a national register of cardiovascular implant devices with respective hospital records, deterministic linkage rules using 2 or 3 indirect patient-level identifiers (i.e. date of birth, sex, admission date) and hospital ID produced linkages with sensitivity of 95% and specificity of 98% compared with a gold standard linkage rule using a combination of both direct and indirect identifiers (55). In recent year machine-learning modalities such as neural networks have been used to build upon probabilistic record linkage improving the scale and accuracy of record linkage(56).

The challenges associated with data linkage are further explored in Chapter 4.

2.4 Statistical methods

This section gives an overview of statistical methods employed in this body of research. Specific statistical methods relevant to each individual study are detailed in the relevant chapters.

Univariate analysis was performed in Graphpad Prism™ version 7.0. Continuous data was unpaired and therefore analysed using Mann-Whitney U tests. Categorical data were analysed using Fisher's exact tests with proportions presented as percentages. A two-sided p-value of ≤ 0.05 was considered to be statistically significant.

Multivariable regression models analysed statistically independent relationships between patient factors, levels of care and outcomes. All multivariable regression analysis was performed in IBM SPSS™ Statistics version 24. Variables achieving a significance of $p<0.1$ in univariate analysis were entered into the regression models. Multivariate linear regression was used to analyse continuous dependent variables (e.g. hospital length of stay) and binary logistic regression for categorical dependent variables (e.g. 30-day mortality). Variable selection in the regression models was performed using the Enter method in which all variables in a block are entered in a single step. For binary logistic regression, exponentiated beta coefficients were reported as odds ratios with a 95% confidence interval. For linear regression, unstandardised B coefficients were reported along with the 95% confidence interval.

Goodness-of-fit test results were reported for all regression analyses:

- For binary logistic regression, Hosmer-Lemeshow tests reported a chi square to test the models' predictive values. In other words it calculated if the observed event rates matched the expected event rates in population subgroups. The output returned a chi -square value and a p-value with a significant p-value meaning the model was not a good fit.

- For binary logistic regression, Nagelkerke R squared was also used to demonstrate how much variability in the dependent variables were accounted for by the independent variables. Nagelkerke R values range from 0 to 1. A value closer to 1 indicated a better fit of the model.

- For linear regression, an R squared was reported which also demonstrated the degree to which variance in the dependent variable can be explained by the independent variables. Values range from 0 to 1. A value closer to 1 indicated a better fit of the model.

2.5 Outcome Measures

Across the studies conducted, several outcome measures were consistently recorded as detailed below. The variety of outcome measures to choose from was limited by what could be obtained from the TARN database. Measures of functional outcome such as Glasgow Outcome Scale or Return to Work were not available from TARN and therefore not considered for outcome measures in the studies conducted.

2.5.1 30-Day Mortality

The death rate within 30 days of hospital admission has long been a traditional benchmark of institutional quality. For TARN-eligible patients, 30-day mortality is the only mortality metric provided. This is consistent with other national trauma registries (57). Previous studies have shown this to be a reasonable cut-off point for measuring mortality. A TARN study of 69,650 admissions found that just under 5% of patients died within a 93 day period, with only 9% of those deaths occurring after 30 days and mostly in elderly patients with a mean ISS of 13 (58). A Scandinavian trauma registry study of 3332 patients showed a similar 5% mortality after 30 days (59).

For the period of TARN data used throughout this body of work (2014-2016 data), all 30-day mortality figures refer to in-hospital mortality. There was no data available on patients who died after discharge within 30-days of initial hospital admission or patients who died in-hospital after 30 days of admission.

2.5.2 Hospital Length of Stay and Bed Days (Survivors)

Hospital length of stay (LOS) is an accepted outcome measure and surrogate of injury severity (57). In some health systems LOS may be influenced by non health-related factors such as insurance status, and therefore this may need to be adjusted for in statistical analysis (60). In-hospital deaths were excluded as they represented a separate adverse outcome irrespective of length of stay and therefore all LOS analysis throughout the studies is for survivors only.

By common convention, hospital bed days (or bed occupancy rate) is calculated as a total inpatient days divided by total bed days available and given as a percentage (61). Total inpatient days is the sum of all lengths of stay within the hospital over the course of a year. Total bed days available is the total number of hospital beds multiplied by 365. This is a useful metric for assessing hospital occupancy as a whole. For the purposes of this research, trauma-specific admissions were of interest as opposed to overall hospital admissions. For that reason, an alternative definition of bed days was devised which was calculated as a mathematical product of mean length of stay and number of admissions. Similarly, critical care bed days were calculated as mean critical care length of stay multiplied by the number of patients admitted to critical care.

2.5.3 Discharge Destination (Survivors)

Discharge destination outcomes are another commonly measured outcome measure in healthcare. There were multiple discharge destination recorded in the TARN data (Home, Other Acute Hospital, Rehabilitation, Nursing Home, Other Institution, Unknown). In the absence of widely collected functional outcome data in the TARN registry, it was also felt that discharge destination could serve as a suitable surrogate. Whilst mortality outcomes are a relatively crude indicator of long-term patient outcome, the difference between a patient going home or being discharged to a nursing home or rehabilitation facility was felt to add an extra layer of information to give an indication of long-term outcome. Previous studies have shown discharge destination to strongly associate with and be predictive of longer term functional outcome measures such as the Modified Rankin Score (62) and Barthel index (63).

2.5.4 Early Intervention

Early surgical or radiological intervention (henceforth known simply as early intervention) was defined as the performance of any emergency surgical or interventional radiological procedure excluding simple chest drain insertion which occurred within 12 hours of admission. This definition is broadly in keeping with the definition of key emergency interventions as set out by the Utstein template for uniform reporting of data following major trauma. The Utstein template is a Europe-wide consensus on data variables in trauma registry data aiming to enhance national and international comparisons of trauma systems(57).

A limitation of this outcome measure is that traditional definitions of emergency surgery have not included specific timings. The NCEPOD classification of intervention defines procedures as immediate (performed within minutes of decision to operate), urgent (intervention takes place within hours), expedited (intervention within days) and elective (routine intervention) (64). The Royal College of Surgeons of England and The European Union of Medical Specialists have both described a 24-hour period as the suggested timeframe for performing emergency surgery (65,66).

Early intervention was an outcome measure in the triage tool study detailed in Chapter 4. A decision was made for the purposes of this study to choose a 12-hour cut-off period for the definition of early intervention as this was deemed to be a clinically relevant period for time-dependent trauma-related surgical and radiological interventions to take place within a timeframe that might be affected by a secondary transfer.

2.5.5 Injury Severity Score

Injury Severity Score (ISS) is an anatomical-based scoring system that gives an overall indication of injury burden. The score is derived from the Abbreviated Injury Score (AIS). AIS scores on a scale of 1 (minor injury) to 6 (incompatible with life) can be obtained for various anatomical regions and describe over 2000 injuries in total. Patients with multiple injuries are scored by adding together the squares of the three highest AIS scores in three predetermined regions of the body. The total is the ISS which can range from 1 to 75. If any injury is assigned an AIS of 6, the ISS is automatically the maximum score of 75. By conventional an ISS>15 is classed as 'major trauma'. This definition stems from studies in the late 1980s showing a significant increase in mortality with ISS> 15 (67). ISS is calculated retrospectively once all the injuries have been identified, limiting its utility as a triage tool. It's primary purpose nowadays is for audit and benchmarking purposes. The advantage of using ISS is that it is already a widely used and understood scoring system and is accepted as the gold standard (68). ISS correlates with mortality, morbidity, hospital stay. Its limitations include the fact that it only considers one injury in each body region. This leads to injuries being overlooked and to less severe injuries occurring in other body regions being included in the calculation over more serious ones in the same body region (69). ISS weights injuries equally thus ignoring for example the disproportionate impact of isolated head injury compared to isolated injuries in less vital body regions. ISS was the injury score provide within the TARN data and so this was used for the studies.

The New Injury Severity Score (NISS) is similar to the ISS and addresses some of the aforementioned limitations. It is calculated using the patient's three most severe injuries irrespective of the body region in which they occur. In other words, NISS will take into account multiple organ injuries within the same body cavity rather than assigning a single score to a body cavity. This makes it particularly suitable for calculating injury severity in patients with isolated body region injuries i.e. multiple chest stab wounds. As it retains the same AIS framework as ISS it remains a familiar metric. There is data to suggest it may be a more accurate predictor of trauma mortality, especially in the case of penetrating trauma which is more likely to be concentrated in a single body region.

The Revised Trauma Score (RTS) is a physiological scoring system based on the initial vital signs of the patient. These are Glasgow Coma Scale (GCS), Systolic Blood pressure (SBP) and Respiratory Rate (RR). In contrast to ISS, a lower score indicates a higher severity of injury. The vital sign values are fed into a formula which is more heavily weighted towards GCS to compensate for isolated head injuries (RTS = 0.9368 GCS + 0.7326 SBP + 0.2908 RR).

The Trauma Injury Severity Score (TRISS) utilises a logarithmic regression model to predict probability of survival based on ISS, RTS and age. The coefficients of the model were derived from multiple regression analysis of the Major Trauma Outcome Study database. By incorporating RTS, it therefore takes into consideration patient physiology as well as injury anatomy. Since the TRISS determines a patient's probability of survival (PS), it is useful for evaluating care by comparing actual outcomes to predicted outcomes. Its limitations include those mentioned regarding ISS. In offering a survival probability it does not take into account patient co-morbidities which may have a significant impact on patient outcome independent of injury severity.

Chapter 3: STUDY 1: Triage in Traumatic Brain Injury: Not simply a case of 'Right Place, First Time'

3.1 Introduction

Traumatic brain injury (TBI) is the dominant cause of mortality and disability after injury (48,49). There are an estimated 1.3 million people currently living with a TBI-related disability in the UK with the financial impact estimated to be £15 billion per year due to health and social costs, loss of economic output and among other things increased criminal activity due to the cognitive and behavioural impacts of TBI (70). TBI from blunt and/or penetrating injury may result in isolated or combined pathology requiring specialist neurosurgical input, such as skull fractures, haematoma (extradural, subdural, subarachnoid and intraparenchymal) as well as diffuse axonal injuries and brainstem injuries. Rapid diagnosis, early neurosurgery and early institution of neurospecialist care are therefore essential functions of a major trauma system (71). Triage tools are designed with high sensitivity, to reduce the risks of poor outcomes due to under-triage and delayed access. However, this tends to reduce specificity, resulting in high over-triage rates and the bypass of patients to MTCs who may not require their specialist services. A recent UK cluster randomised controlled trial of ambulance transfer of TBI patients to either their nearest acute hospital or a specialist neuroscience centre revealed an overtriage ratio of up to 13:1 for neurosurgical requirement and 4:1 for image-proven TBI. In other words only 7% required neurosurgery whilst only 25% had a TBI seen on a diagnostic scan (72). With these considerations in mind, the triage of TBI patients was felt to be a suitable starting point for this thesis.

A high-functioning inclusive trauma system may mitigate the outcome implications of under-triage and secondary transfer. A 2018 study of over 300,000 injured patients identified from the US National Trauma Databank found that whilst only 3.3% of patients were undertriaged, those that were experienced a 32% adjusted increased odds of death compared to appropriately triaged patients (73). Several studies have analysed the impact of secondary transfer in TBI patients on outcomes with varying results (74–77). In a diagnostic cohort study of over 6500 TARN patients, the existing LAS triage tool demonstrated a sensitivity of 45%, suggesting a considerable proportion of patients with severe TBI first arrive at TUs. Whilst this may highlight a need for more sensitive triage tools, it also highlights the real and present need to maintain diagnostic and management expertise of TBI at TUs, pending the transfer of these patients to an MTC (78).

Neurospecialist care encompasses neurosurgical procedures and invasive intracranial pressure monitoring, which may take place on dedicated neuro-intensive care units. For the most part these capabilities are confined to MTCs with the exception of a small number of neurosurgery-capable TUs. These specialist TUs function as tertiary referral units for non-traumatic neurosurgical conditions such as brain tumours and neurovascular emergencies, however they lack the full panoply of expertise required to manage polytrauma patients and hence don’t fulfil the requirements of an MTC. Only in select isolated TBI cases might patients be primarily triaged to one of these units. National guidance for the management of TBI recommends CT scanning and reporting within 1 hour of hospital arrival and transfer to specialist neurosurgical units or MTCs for all patients with suspicion of severe TBI (such as GCS <8), irrespective of the need for surgical intervention (45,49,79).

Conservative management of TBI includes supportive ward-based non-operative care and close monitoring of vital signs and neurological signs including gross limb motor function, GCS and pupillary size for any evidence of neurological deterioration. Patients may undergo repeat cross-sectional imaging as guided by changes in these signs or at set time intervals on the advice of neurosurgical teams at a regional MTC. Patients showing signs of neurological deterioration may then be transferred to the MTC for neurospecialist care if required. This conservative level of care is offered at TUs but can equally be the only treatment required for TBI patients at MTCs in the event of overtriage or where that MTC functions as a TU for its local population.

TBI is commonly categorised according to severity as mild, moderate or severe as defined by the AIS. This particular scoring system was developed by the American Medical Association Committee on Medical Aspects of Automotive Safety and published in the early 1970s as a means for researchers to have a consistent method and language for comparing tissue damage injuries acquired in automobile crashes (80,81). AIS scores on a scale of 1 to 6 can be obtained for various anatomical regions and comprise the overall Injury Severity Score (see Chapter 2.5.5). An AIS score of 1 generally does not require inpatient hospital treatment whereas a score of 6 is invariably fatal. Several retrospective studies have analysed head AIS scores alongside GCS and patient outcomes to divide TBI into the aforementioned categories. A comprehensive Israeli study of over 51000 TBI patients determined that AIS scores of 2 or less equate to 'mild' TBI, AIS scores of 3 to 4 equate to 'moderate' TBI and an AIS of 5 or above equates to 'severe' TBI (82). This categorisation is in broad agreement with a number of other preceding studies (83).

When considering the outcomes of TBI patients managed across an inclusive system it is helpful to understand these outcomes across a wide spectrum of treatment settings and injury severity. It remains unclear whether patients within a developed urban healthcare setting are significantly harmed by delays to neurospecialist care caused by secondary triage from TUs. Conversely, the system may benefit from a more selective approach to MTC admissions which can be facilitated by directing more patients towards TUs in the first instance. There is also little evidence regarding the outcomes of patients managed conservatively at TUs compared to those conservatively managed at MTCs.

The aim of the study was to determine the outcomes of patients with isolated moderate and severe TBI managed across an inclusive trauma system. The specific objectives were as follows:

For patients requiring neurospecialist care:

- Determine whether outcomes were different for those initially triaged to a TU and later transferred to an MTC compared to those primarily admitted to an MTC.

For patients managed conservatively:

- Determine whether outcomes were different for those managed at TU compared to those managed at an MTC (excluding patients transferred for ongoing conservative management).

3.2 Methods

A retrospective cohort study was conducted which included all adult patients with moderate and severe isolated TBI managed across the London Major Trauma System (LMTS).

3.2.1 Setting and participants

De-identified Trauma Audit and Research Network (TARN) registry data was obtained for all patients aged 16 and over with an isolated moderate or severe TBI admitted to hospitals within the LMTS over a 3-year period between 1st January 2014 and 31st December 2016. At the time of commencing the study, 2016 was the most recent year with a full set of TARN data available. It was agreed during departmental meetings that 3 years' worth of data would provide a suitable number of subjects for the study. Isolated TBI was defined as Abbreviated Injury Scale (AIS) Head ≥3, and AIS all other body regions <3. The setting of the study was the London Major Trauma System, the structure of which is described in detail in Chapter 1.2.6.

NHS Research Ethics Committee approval was not required for this study in accordance with Health Research Authority guidance(50).

3.2.2 Variables

The patients were divided into 2 broad populations: those who required neurospecialist care during their admission (NSC group) and those who were managed conservatively (CONS group). The reason for this categorisation was that in the LMTS, neurocritical care capabilities were largely confined to the 4 MTCs, therefore the need for neurospecialist care was by definition a justification for admission to one of these MTCs. As detailed in the aforementioned objectives, the exposure being analysed was the initial hospital destination and how this triage decision impacted on outcomes for both patients who did eventually require MTC admission and those who may have only required TU-level care but who also ended up in an MTC setting. A list of data fields obtained from the TARN database is listed in Table 3.1.

In the NSC cohort comparisons were made between those triaged directly to an MTC (NSC-DIRECT) versus those initially triaged to a TU but who later required transfer to an MTC for their neurospecialist intervention to take place (NSC-TRANSFER). In the conservative cohort the comparison was between those initially triaged to an MTC (CONS-MTC) versus those triaged to a TU and who remained at a TU because they did not require neurospecialist care (CONS-TU). Conservative management included patients admitted to critical care but who did not require neurosurgery or invasive intracranial pressure monitoring. The primary outcome analysed was 30-day mortality. Secondary outcomes were discharge destination and hospital length of stay. A more detailed explanation and rationale for these outcome measures and others used throughout this thesis is provided in Chapter 2.5.

The London Triage Tool, which triggers MTC admission based on physiological, anatomical, mechanistic or other special criteria was used to determine the initial hospital destination for each patient. In the context of TBI for example, a patient with a GCS of ≤13 or a suspected open/depressed skull fracture would trigger direct admission to an MTC.

Demographics	• Admission Age (E) • Gender (E)
Injury characteristics	• Admission Glasgow Coma Score (GCS) (E) • Need for pre-hospital intervention (E) • Injury Severity Score (E) • TBI pathology
In-hospital treatment	• Operative procedure performed
Outcomes	• 30-day mortality (D) • Discharge destination (survivors only) • Hospital length of stay (survivors only) (D) • Intensive Care Unit admission (E) • Intensive Care Unit length of stay

Table 3.1: Data extracted from TARN registry

(E) Explanatory and (D) Dependent variables used for regression analysis

The neurospecialist care and conservative treatment cohorts were further sub-divided according to age with patients aged 16-69 categorised as ‘adults’ and those aged 70 and over categorised as ‘elderly’. This age cut-off was adopted in accordance with the LMTS `Elderly Trauma guidelines’ (84).

3.2.3 Bias

Admissions to two specialist neurosurgery-capable TUs within the LMTS were excluded from this study as it was felt that the neurosurgical resources available at these institutions would be significant confounding factors in any analysis comparing outcomes between MTCs and TUs. In particular, for comparison of outcomes between CONS-MTC and CONS-TU the results may have been skewed by the outcomes of patients managed at TUs with the neurospecialist resources of an MTC. From the initial de-identified patient data obtained from TARN, a total of 47 patients over the 3-year study period fell into the category of being admitted to neurosurgery-capable TUs and were therefore excluded from the outset. This excluded group was not deemed worthy of specific analysis owing to the small numbers and also the subsequent change in LMTS policy from 2019 that stopped all isolated neurotrauma patients being admitted to neurosurgery-capable TUs.

Similarly, any CONS-TU patients transferred to MTCs for ongoing conservative care were also excluded from analysis as this would have added further confounding bias to the comparison of conservative treatments at TUs versus conservative treatment at MTCs by having patients who had been exposed to both treatment settings.

3.2.4 Statistical Methods

Univariate analysis was performed in Graphpad Prism (version 7 for Mac OS X, GraphPad Software, La Jolla California USA). Kolmogorov-Smirnov tests showed all continuous variables to be not normally distributed and these were therefore analysed using Mann-Whitney U tests. Categorical data were analysed using Fisher's exact tests with proportions presented as percentages. A p-value of ≤ 0.05 was considered to be statistically significant.

Multivariable regression models analysed statistically independent relationships between patient factors, levels of care and outcomes. The main dependent and explanatory variables are identified in Table 3.1. Variables achieving significance of $p<0.1$ in univariate analysis were entered into the regression models. Multivariate linear regression was used to analyse the continuous dependent variable of hospital length of stay and binary logistic regression was used for the categorical dependent variable of 30-day mortality. Results of logistic regression were reported as adjusted odds ratios (OR) with 95% confidence intervals whilst linear regression was reported as B coefficients with 95% confidence intervals. An OR of greater than 1 indicated an increased mortality odds. All multivariable regression analysis was performed in IBM SPSS Statistics version 24. Hosmer-Lemeshow tests and Nagelkerke R squared values are reported for each regression model beneath the respective tables. A further explanation of these measures and their implication for model interpretation is provided in Chapter 2.4 (Statistical Methods).

3.3 Results

A total of 6199 patients with moderate and severe traumatic brain injury were managed by the London Trauma System over the three-year period. Seven hundred and forty-six (12%) patients received neuro-specialist care (NSC group) and 5453 (88%) were managed conservatively (CONS group). In the conservative group, 642 patients who had been transferred from TUs to MTCs to **continue receiving conservative treatment** were excluded leaving 4811 conservative patients for analysis and an overall total of 5557 patients across both treatment groups (Figure 3.1).

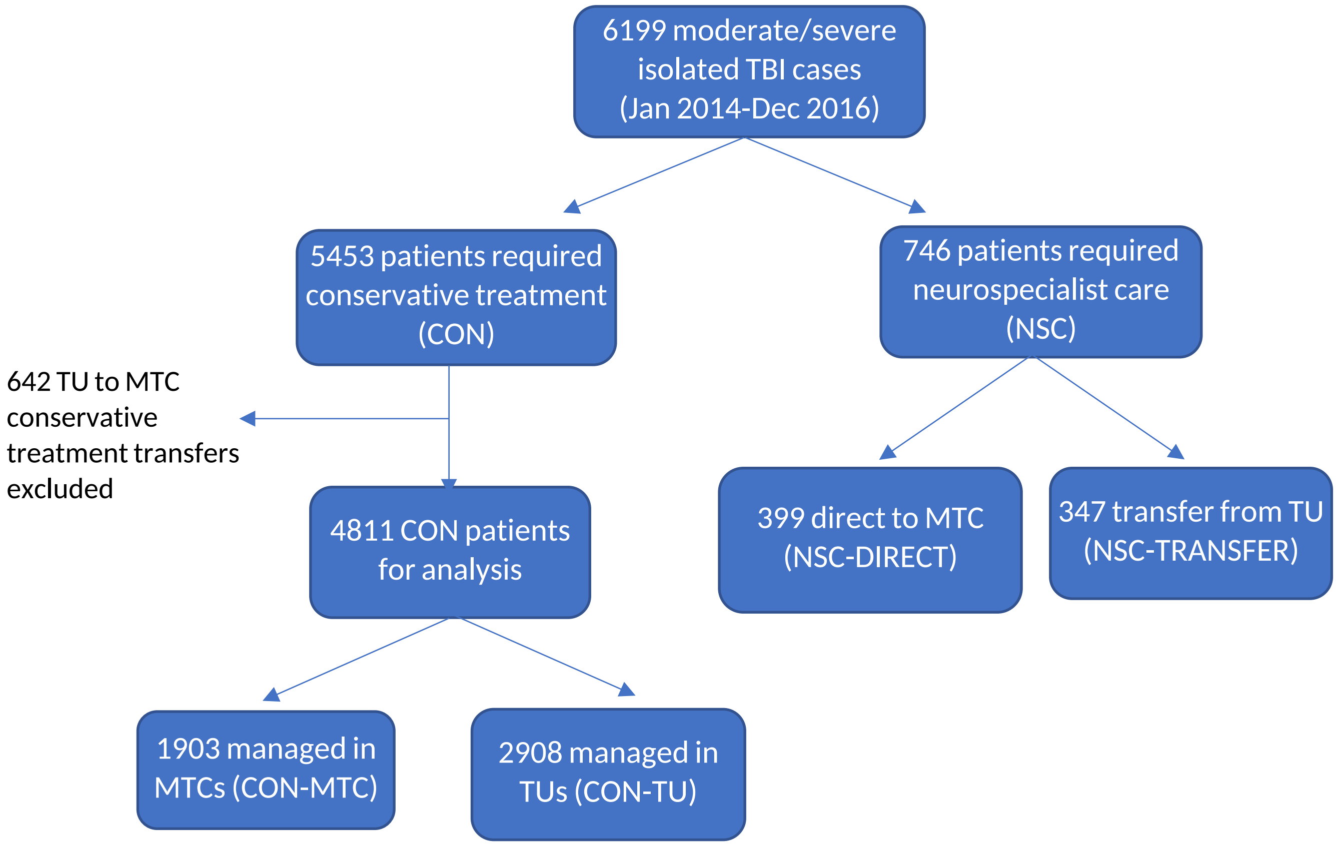


Figure 3.1: Selection and exclusion criteria

3.3.1 Neuro-Specialist Care Patients

Just over half (53%) of the 746 NSC patients were triaged directly to MTCs from scene (Table 3.2). Compared to NSC-TRANSFER, the NSC-DIRECT patients were younger (median age 49 vs 66 years, p<0.01), had a lower admission GCS (median 10 vs 14, p<0.01) and were more severely injured with an ISS spread across a higher range (median ISS with interquartile range 25(25-29) vs 25(20-25), p<0.01). NSC-DIRECT patients were also more likely to be intubated prior to hospital arrival (32% vs 0%, p<0.01). There was no significant difference in gender distribution between the NSC triage groups. The significant difference between triage groups persisted when the groups are divided by age into adult and elderly cohorts, with the exception being age in the elderly group as there was no longer a significant age difference between elderly NSC-DIRECT and elderly NSC-TRANSFER. A total of 43 patients had no GCS data recorded and 9 had no known discharge destination. No other missing data was noted.

	ALL AGES		**ADULT (16-69)**		**ELDERLY (70 AND OVER)**	
Triage status	**NSC-DIRECT**	**NSC-TRANSFER**	**NSC-DIRECT**	**NSC-TRANSFER**	**NSC-DIRECT**	**NSC-TRANSFER**
N	**399**	**347**	**311**	**191**	**88**	**156**
Data are presented as ≠n (%) or ᵻmedian (IQR)						
Demographics and injuries						
Admission Age (years) ᵻ	49 (31-68)*	66 (46-80)	41 (28-56)*	49 (34-59)	79 (73-84)	80 (76-85)
Male≠	307 (77)	249 (72)	254 (82)	150 (79)	53 (60)	99 (63)
Admission GCSᵻ	10 (6-14)*	14 (12-15)	9(5-14)*	14(9-15)	14(10-15)*	15 (14-15)
Pre-hospital intubation≠	128 (32)*	0 (0)	116 (37)*	0 (0)	12 (14)*	0 (0)
ISSᵻ	25 (25-29)*	25 (20-25)	25 (25-29)*	25 (20-25)	25 (25-26)*	25 (25-25)
Outcomes						
Hospital LOS (days) ᵻ	26 (12-45)*	14 (6-25)	26 (12-47)*	17 (6-29)	23 (11-40)*	10 (6-21)
ICU admission≠	309 (77)*	138 (54)	261 (84)*	130 (63)	48 (55)*	52 (37)
ICU LOS (days) ᵻ	12 (4-20)*	8 (3-15)	13 (5-20)*	8 (4-16)	4 (2-10)	7 (2-13)
Home discharge≠	157 (47)	140 (45)	130 (48)	94 (55)	27 (43)	46 (33)
Discharge to other acute hospital≠	107 (32)*	132 (42)	87 (32)	60 (35)	20 (32)*	72 (52)
Discharge to rehab≠	58 (17)*	31 (10)	46 (17)*	17 (10)	12 (19)	14 (10)
Discharge to nursing home/other/unknown≠	13 (4)	8 (3)	9 (3)	1 (0.5)	4 (6)	7 (5)
30-day mortality≠	64 (16)*	36 (10)	39 (13)	19 (10)	25 (28)*	17 (11)

Table 3.2: Neurospecialist care patients- Demographics and outcomes

GCS= Glasgow Coma Scale, ISS= Injury Severity Score, MTC= Major Trauma Centre, TU= Trauma Unit ICU= Intensive Care Unit, LOS= Length of stay, NUR=Non-usual residence (i.e. rehabilitation unit, nursing care home or other institution)
*indicates statistically significant difference (p≤0.05) between NSC-Direct and NSC-Transfer patients within each age cohort
Discharge destination and lengths of stay given for survivors only
20 NSC-Transfer adult patients and 10 Transfer elderly patients with no recorded GCS, 10 MTC adult patients and 3 MTC elderly patients with no recorded GCS

Overall mortality was 13.4% among the NSC patient group. Unadjusted mortality was significantly higher in the NSC-DIRECT group overall (16% vs 10%, p=0.02), principally due to significant mortality differences within the elderly population (28% vs 11%, p<0.01) (Fig. 3.2). When applying multivariate regression analysis to control for injury characteristics, adult patients had equivalent mortality outcomes regardless of triage decision, while elderly NSC-DIRECT patients were more than twice as likely to die than the NSC-TRANSFER group (OR 2.42 (1.06-5.54), p=0.04), (Fig. 3.3, Table 3.3). Full regression output data for all age groups can be found in Appendix 7.

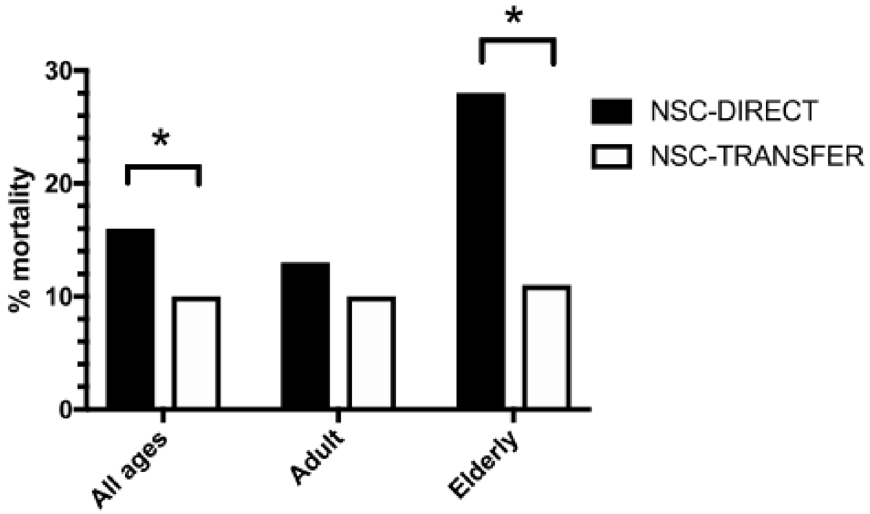


Figure 3.2: Neuro-specialist care 30-day mortality

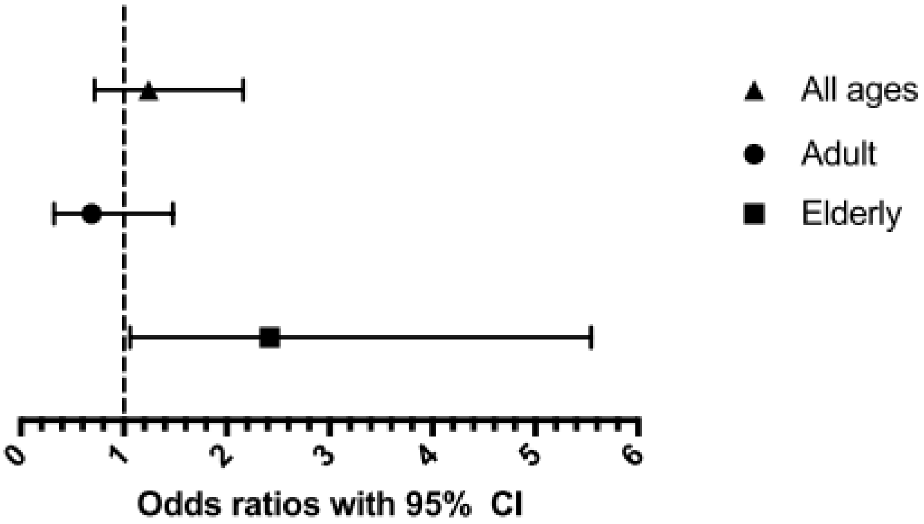


Figure 3.3: Independent effect of direct MTC admission on 30-day mortality (neuro-specialist)

Other variables independently associated with increased 30-day mortality among all age groups were age (OR 1.05 (1.03-1.06), p<0.01) and reduced admission GCS (OR 0.9 (0.84-0.95), p<0.01). The strongest single mortality predictor was the need for ICU admission which was associated with a greater than six-fold increase in 30-day mortality odds (OR 6.39 (2.89-14.12), p<0.01). In the elderly, ICU admission was associated with a 12-fold increase in 30-day mortality odds (OR 12.26 (4.41-34.6), p<0.01).

30-DAY MORTALITY						
Independent variables	**All Ages**		**Adult (16-69)**		**Elderly (70 and over)**	
	OR (95% CI)	***p* *value***	**OR (95% CI)**	***p* *value***	**OR (95% CI)**	***p* *value***
Admission Age	1.05 (1.03-1.06)	<0.01	1.05 (1.02-1.07)	<0.01	1.09 (1.02-1.17)	0.01
Admission GCS	0.90 (0.84-0.95)	<0.01	0.84 (0.77-0.91)	<0.01	0.98 (0.87-1.10)	0.73
ISS	1.03 (0.98-1.09)	0.21	1.03 (0.96-1.10)	0.46	1.06 (0.94-1.19)	0.35
Prehospital Intubation	1.06 (0.55-2.05)	0.86	1.26 (0.58-2.75)	0.56	0.97 (0.22-4.27)	0.97
ICU admission	6.39 (2.89-14.12)	<0.01	2.49 (0.68-9.09)	0.17	12.36 (4.41-34.60)	<0.01
Initial Triage Destination (MTC)	1.24 (0.72-2.16)	0.44	0.69 (0.32-1.48)	0.34	2.42 (1.06-5.54)	0.04

Table 3.3: Binary logistic regression analysis of factors associated with 30-day mortality in neurospecialist patients

GCS: Coma Scale, ISS: Injury Severity Score, OR: Odds ratio, CI: Confidence Interval.,
Mortality n=746 (adult=502, elderly=244), Nagelkerke R-squared = All Ages: 0.23, Adult: 0.20, Elderly: 0.32**.** Hosmer-Lemeshow test: All Ages: 10.2, p=0.25; Adult: 13.35, p=0.1; Elderly: 4.64, p=0.80

SURVIVOR LENGTH OF STAY						
	B coeff. (95% CI)	***p* *value***	**B coeff. (95% CI)**	***p* *value***	**B coeff. (95% CI)**	***p* *value***
Admission Age	0.14 (0.04-0.23)	0.01	0.22 (0.05-0.39)	0.01	0.16 (-0.28-0.60)	0.48
Admission GCS	-1.26 (-1.88- (-0.64))	<0.01	-1.42 (-2.17-(-0.67))	<0.01	-0.46 (-1.62-0.69)	0.43
ISS	0.55 (0.17-0.93)	0.01	0.60 (0.13-1.06)	0.01	0.23 (-0.40-0.86)	0.47
Prehospital Intubation	-1.94 (-8.08-4.20)	0.54	-0.80 (-7.87-6.28)	0.83	-13.93 (-30.38-2.52)	0.1
ICU admission	15.33 (10.34-20.31)	<0.01	15.61 (8.63-22.58)	<0.01	14.63 (8.05-21.20)	<0.01
Initial Triage Destination (MTC)	9.52 (5.09-13.94)	<0.01	8.24 (2.37-14.11)	0.01	12.5 (6.58-18.48)	<0.01

Table 3.4: Linear regression analysis of factors associated with survivor length of stay in neurospecialist patients

GCS: Coma Scale, ISS: Injury Severity Score, B coeff: Beta coefficient
Length of stay n=646 (adult=444, elderly=202) following exclusion of 100 non-survivors. Model R-squared with ANOVA p-values= All Ages: 0.24, p<0.01; Adult: 0.24, p=0.01; Elderly: 0.23, p<0.01

A breakdown of the NSC group by type of TBI pathology and neurosurgical intervention (Table 3.5) revealed similar rates of extradural haematoma (EDH) between NSC-DIRECT and NSC-TRANSFER (5% vs 5%, p=0.87) and a significantly lower proportion of subdural haematoma (SDH) among the NSC-DIRECT patients (17% vs 52%, p<0.01). Within the NSC-DIRECT group there was a higher proportion of TBI pathologies which have traditionally been less amenable to curative neurosurgical intervention such as combined intracranial haemorrhage (33% vs 18%, p<0.01), brainstem injury (30% vs 19%, p<0.01) and diffuse axonal injury (12% vs 2%, p<0.01). This is further reflected in the higher proportion of EDH/SDH evacuations among NSC -TRANSFER patients (73% vs 88%, p<0.01). Among those that did have EDH/SDH evacuation, 30-day mortality was higher in the NSC-DIRECT group (17% vs 9%, p=0.01). These significant findings were similarly reflected within the elderly population which also demonstrated higher rates of traditionally inoperable pathology (brainstem injury 31% vs 12%, p<0.01) and fewer EDH/SDH evacuations in NSC-DIRECT patients (88% vs 96%, p=0.04) along with higher mortality rates in NSC-DIRECT patients who underwent EDH/SDH evacuation (26% vs 9%, p<0.01).

Pathology/Procedure	**All Ages**			**Elderly (70 and over)**		
TRIAGE STATUS	**NSC-DIRECT**	**NSC-TRANSFER**		**NSC-DIRECT**	**NSC-TRANSFER**	
N	**399**	**347**		**88**	**156**	
Data are presented as n (% within triage group)						
			TBI PATHOLOGY			
			p-value			**p-value**
EDH only*	20 (5)	19 (5)	0.87	1 (1)	1 (0.6)	>0.99
SDH only*	66 (17)	179 (52)	<0.01	33 (38)	112 (72)	<0.01
SAH only*	18 (5)	12 (4)	0.58	4 (5)	4 (3)	0.46
Combined ICH*	131 (33)	64 (18)	<0.01	19 (22)	20 (13)	0.10
Brainstem injury +/- other pathology	123 (30)	67 (19)	<0.01	27 (31)	19 (12)	<0.01
DAI +/- other pathology	47 (12)	8 (2)	<0.01	6 (7)	1 (0.6)	0.01
			NEUROSURGICAL PROCEDURES			
Evacuation EDH/SDH*[2]	290 (73)	306 (88)	<0.01	77 (88)	149 (96)	0.04
Craniectomy only*[3]	9 (2)	3 (1)	0.16	3 (3)	0 (0)	0.05
ICP monitoring only	81 (20)	29 (8)	<0.01	7 (8)	6 (4)	0.23
Other	19 (5)	9 (3)	0.13	1 (1)	1 (0.6)	>0.99
			30-DAY MORTALITY			
EDH only*	1 (5)	0	>0.99	1 (100)	1 (100)	>0.99
SDH only*	8 (12)	11 (6)	0.17	6 (18)	7 (6)	0.07
SAH only*	2 (11)	2 (17)	>0.99	1 (25)	1 (25)	>0.99
Combined ICH*	18 (14)	8 (13)	>0.99	9 (47)	4 (20)	0.10
Brainstem injury +/- other pathology	33 (27)	14 (21)	0.39	9 (33)	5 (26)	0.75
DAI +/- other pathology	6 (13)	2 (25)	0.34	4 (67)	1 (100)	>0.99
Evacuation EDH/SDH*[2]	50 (17)	29 (9)	0.01	20 (26)	14 (9)	<0.01
Craniectomy only*[3]	1 (11)	0 (0)	>0.99	0 (0)	0 (0)	>0.99
ICP monitoring only	12 (15)	7 (24)	0.26	4 (57)	3 (50)	>0.99
Other	1 (5)	0 (0)	>0.99	1 (100)	0 (0)	>0.99

Table 3.5: Comparison of TBI pathology, neurosurgical procedures and 30-day mortality between triage groups in neurospecialist patients

EDH= Extradural haemorrhage, SDH= Subdural haemorrhage, SAH= Subarachnoid haemorrhage, ICH= Intracerebral haemorrhage, DAI= Diffuse axonal injury, ICP= Intracranial pressure
*includes concomitant skull fracture but no brainstem/DAI
*[2]via burrhole/craniotomy

Across all 646 NSC survivors, length of stay was longer for the NSC-DIRECT group (26 vs 14 days, p<0.01), and this difference persisted after adjustment for admission variables (Table 3.4). Other independent predictors of longer length of stay were increased age, reduced GCS, increased ISS and admission to ICU. In the elderly only ICU admission and direct MTC admission were independently associated with longer lengths of stay.

A total of 297 patients were discharged directly home (46%). There was no significant difference in rates of home discharge between NSC-DIRECT and NSC-TRANSFER patients in any age group (Figs. 3.4). Proportionately more elderly NSC-DIRECT survivors were discharged to rehabilitation facilities (19% vs 10%, p=0.11) while elderly NSC-TRANSFER patients were more likely to be discharged back to an acute hospital (52% vs 32%, p=0.01) (Table 3.2).

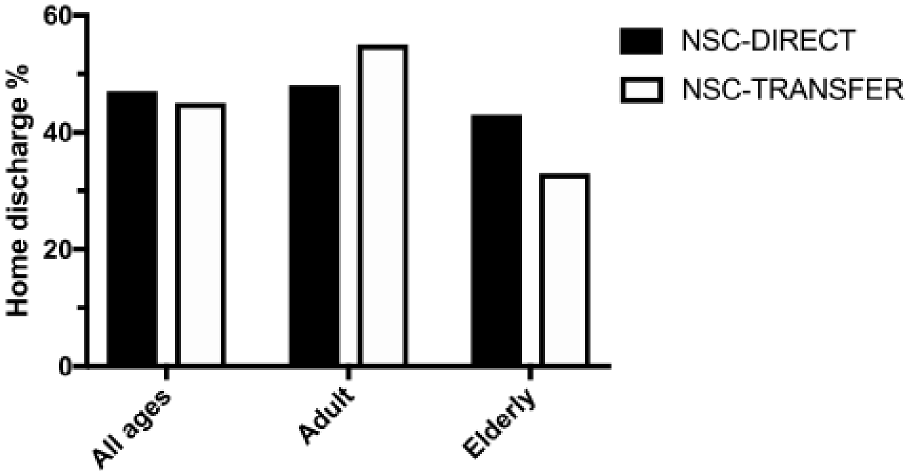


Figure 3.4: Neuro-specialist care home discharge

3.3.2 Conservative Management Patients

Most conservatively managed patients (60%) were managed exclusively at TUs (CONS-TU). The conservatively managed MTC patients (CONS-MTC) were younger (age 58 v 80, p<0.01), more often male (71% vs 55%, p<0.01), had a lower admission GCS (14 v 15, p<0.01) and higher ISS (20 v 17, p<0.01) than those managed conservatively at TUs (Table 3.6). A total of 207 patients within the 4811 analysed had no recorded GCS data and 59 patients had no known discharge destination. No other missing data was noted.

	ALL AGES		ADULT		ELDERLY	
Triage status	**CONS-MTC**	**CONS-TU**	**CONS-MTC**	**CONS-TU**	**CONS-MTC**	**CONS-TU**
N	**1903**	**2908**	**1206**	**906**	**697**	**2002**
Data are presented as ≠n (%) or †median (IQR)						
Demographics and injuries						
Admission Age (years) †	58 (36-77)*	80 (62-88)	42 (29-56)*	49 (35-60)	82 (76-87)*	85 (79-90)
Male≠	1344 (71)*	1605 (55)	939 (78)	678 (75)	405 (58)*	927 (46)
Admission GCS≠	14 (10-15)*	15 (14-15)	14 (10-15)*	15 (14-15)	14 (11-15)*	15 (14-15)
Pre-hospital intubation≠	257 (14)*	5 (0.2)	186 (15)*	1 (0.1)	71 (10)*	4 (0.2)
ISS†	20 (16-25)*	17 (16-25)	20 (16-25)*	17 (16-25)	21 (16-25)*	17 (16-25)
Outcomes						
Hospital LOS (days) †	9 (5-19)*	7 (4-16)	7 (4-16)*	4 (3-8)	13 (7-26)*	10 (5-21)
ICU admission≠	521 (27)*	120 (4)	371 (31)*	72 (8)	150 (22)*	43 (2)
ICU LOS (days) †	3 (2-9)*	2 (1-4)	3 (1-8)*	1 (1-4)	4 (2-10)*	2 (1-4)
Home discharge≠	1241 (75)*	1606 (61)	914 (80)*	591 (67)	327 (63)	1015 (58)
Discharge to other acute hospital≠	210 (13)*	464 (18)	112 (10)*	246 (28)	98 (19)*	218 (12)
Discharge to rehab≠	108 (7)	153 (6)	64 (6)*	19 (2)	44 (8)	134 (8)
Discharge to nursing home≠	55 (3)*	334 (13)	11 (1)	9 (1)	44 (8)*	325 (19)
Discharge to other institution/unknown≠	46 (3)	84 (3)	36 (3)	23 (3)	10 (2)	61 (3)
30-day mortality≠	243 (13)*	267 (9)	69 (6)*	18 (2)	174 (25)*	249 (12)

Table 3.6: Patients receiving conservative care- Demographics and outcomes

GCS= Glasgow Coma Scale, ISS= Injury Severity Score, MTC= Major Trauma Centre, TU= Trauma Unit ICU= Intensive Care Unit, LOS= Length of stay NUR= Non-usual residence (i.e. rehabilitation unit, nursing home or other institution). Discharge destination and lengths of stay given for survivors only.
*indicated significant difference (p≤0.05) between MTC and TU within the particular age group
50 TU adult patients and 114 TU elderly patients with no recorded GCS, 23 MTC adult patients and 20 MTC elderly patients with no recorded GCS

Overall 30-day mortality was 11% in CONS patients. Unadjusted mortality was significantly lower in CONS-TU across all age categories, with the biggest difference between TU and MTC patients seen in the elderly (25% vs 12% p<0.01) (Fig. 3.5). When adjusting for confounders however, there were no significant differences in 30-day mortality odds (Fig. 3.6, Table 3.7). As with the NSC group of patients, advanced age and higher admission GCS were significant independent predictors of increased 30-day mortality, with ICU admission having a weaker association with mortality in the CONS group (OR 1.78 (1.22-2.60) p<0.01) compared to NSC (6.39 (2.89-14.12), p<0.01).

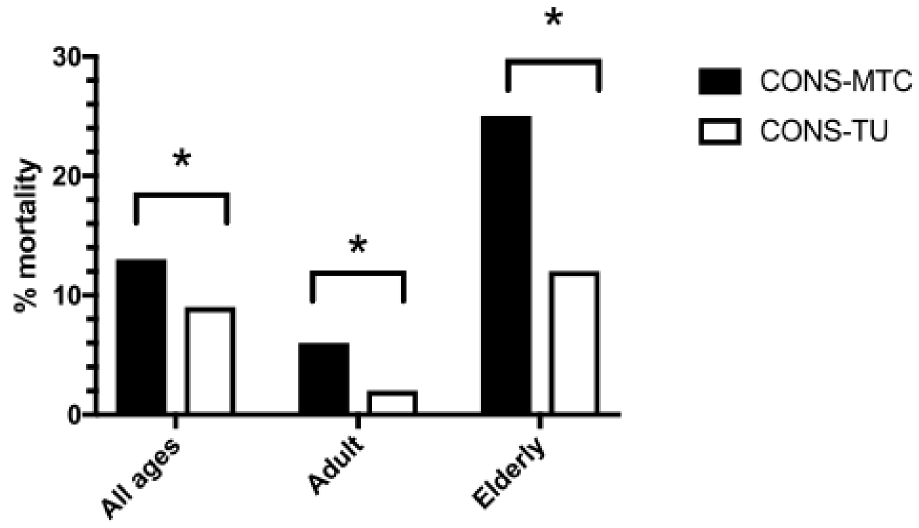


Figure 3.5: Conservative care 30-day mortality

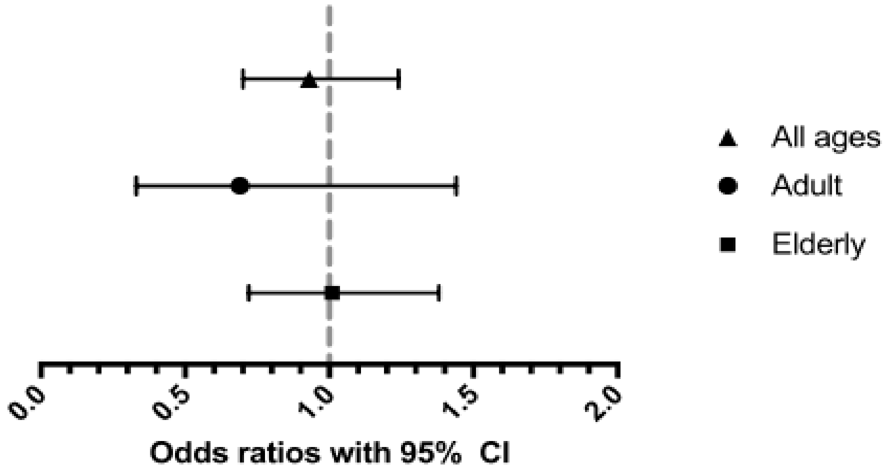


Figure 3.6: Independent effect of direct MTC admission on 30-day mortality (conservative)

30-DAY MORTALITY						
Independent variables	**All Ages**		**Adult (16-69)**		**Elderly (70 and over)**	
	OR (95% CI)	***p value***	**OR (95% CI)**	***p value***	**OR (95% CI)**	***p value***
Admission Age	1.08 (1.07-1.09)	<0.01	1.06 (1.04-1.08)	<0.01	1.09 (1.07-1.11)	<0.01
Admission GCS	0.71 (0.68-0.74)	<0.01	0.72 (0.67-0.77)	<0.01	0.70 (0.66-0.73)	<0.01
ISS	1.11 (1.09-1.13)	<0.01	1.14 (1.08-1.19)	<0.01	1.10 (1.07-1.13)	<0.01
Prehospital Intubation	1.38 (0.85-2.22)	0.19	1.65 (0.84-3.2)	0.15	1.04 (0.51-2.13)	0.91
ICU admission	1.78 (1.22-2.60)	<0.01	2.56 (1.34-4.92)	0.01	1.52 (0.93-2.48)	0.09
Initial Triage Destination (MTC)	0.93 (-.70-1.24)	0.61	0.69 (0.33-1.44)	0.32	1.01(0.73-1.38)	0.96

Table 3.7: Binary logistic regression analysis of factors associated with 30-day mortality in conservative patients

GCS: Glasgow Coma Scale, ISS: Injury Severity Score, OR: Odds ratio, CI: Confidence Interval.
Mortality n=4811 (adult= 2112, elderly=2699) Nagelkerke R-squared = All Ages: 0.44, Adult: 0.49, Elderly: 0.38; Hosmer-Lemeshow test: All Ages: 2.60, p=0.96; Adult: 5.84, p=0.67; Elderly: 13.79, p=0.09

SURVIVOR LENGTH OF STAY						
	B coeff. (95% CI)	***p* *value***	**B coeff. (95% CI)**	***p value***	**B coeff. (95% CI)**	***P value***
Admission Age	0.22 (0.19-0.25)	<0.01	0.17 (0.12-0.21)	<0.01	0.11 (-0.01-0.23)	0.08
Admission GCS	-1.38 (-1.66-(-1.11))	<0.01	-1.39 (-1.68- (-1.11))	<0.01	-1.40 (-1.98-(-0.82))	<0.01
ISS	0.27 (0.17-0.36)	<0.01	0.28 (0.16-0.40)	<0.01	0.25 (0.11-0.40)	<0.01
Prehospital Intubation	-5.38 (-8.72- (-2.05))	0.02	-5.57 (-8.88-(-2.27))	0.01	-6.88 (-15.70-1.94)	0.13
ICU admission	8.47 (6.36-10.59)	<0.01	8.63 (6.42-10.84)	<0.01	8.38 (3.89-12.87)	<0.01
Initial Triage Destination (MTC)	2.91 (1.62-4.20)	<0.01	3.88 (2.31-5.44)	<0.01	1.95 (-0.15-4.05)	0.07

Table 3.8: Linear regression analysis of factors associated with survivor length of stay in conservative patients

GCS: Glasgow Coma Scale, ISS: Injury Severity Score, CI: Confidence Interval., B coeff: Beta coefficient
Length of stay n=4301 (adult=2026, elderly=2276). Further exclusions: Non-survivors (n=510). Model R-squared values (all ANOVA p-values <0.01)= All Ages: 0.11, Adult: 0.17, Elderly: 0.037

Length of stay was longer for CONS-MTC survivors (9 v 7 days, p<0.05) (Table 3.6). After adjustment for confounding variables, MTC admission was independently associated with a longer length of stay in the adult population but not the elderly (Table 3.8). Age, GCS, ISS, prehospital intubation and need for ICU admission were all independent predictors of length of stay, with ICU admission having the biggest single effect (beta coefficient 8.47 (6.36-10.59), p<0.01). However, within the elderly cohort specifically, age itself was no longer a significant independent predictor of length of stay.

A total of 2847 CONS patients were discharged home (59%). In univariate analysis the largest difference was specifically seen in adult patients with CONS-MTC more likely to go home (80% vs 67%, p<0.01) (Fig. 3.7). Adult CONS-TU patients were more likely to be discharged to another acute hospital compared to CONS-MTC (28% vs 10%, p<0.01), however this pattern was reversed in the elderly (12% vs 19%, p<0.01) (Table 3.6). In adults, more MTC patients were discharged to rehabilitation (6% vs 2%, p<0.01) and in the elderly, significantly more TU patients were discharged to nursing care homes (19% vs 8%, p<0.01). Full regression output data for all age groups can be found in Appendix 7.

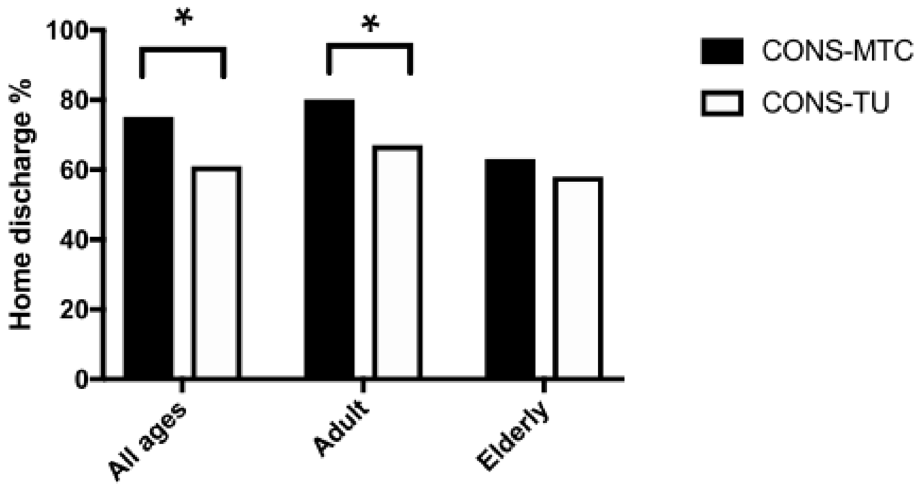


Figure 3.7 : Conservative care home discharge

3.4 Discussion

This multisite cohort study examined outcomes for patients with TBI across an inclusive trauma system based on triage destination. In total, 16% of patients required secondary transfer from TU to MTC (which drops to 6% when excluding patients transferred to continue conservative management for reason explained in section 3.2.3). Overall, adjusted mortality and discharge outcomes for patients receiving neurospecialist care at MTCs were no different if they were initially 'under-triaged' to a TU. Notably, in the elderly group of neurospecialist care patients, adjusted mortality odds were found to be higher in patients triaged directly to MTCs. Overall adjusted mortality outcomes for patients managed conservatively were no different regardless of whether patients were admitted to MTCs or TUs. Conservative patients managed at MTCs were more likely to be discharged home despite spending longer in hospital.

Elderly patients who required neurospecialist care were more likely to be admitted to a trauma unit initially. This is in keeping with a TARN report into major trauma in older people which found that not only were injured elderly patients less likely to be primarily taken to an MTC, but they were also less likely to be transferred from a TU to an MTC and had longer times to investigation and treatment (85). The report examined major trauma admissions in England and Wales throughout 2014 and found that amongst patients with serious head injuries (AIS head 3+) who were initially admitted to a TU 46% of those aged 60 and over were transferred to an MTC compared to 66% of those aged under 60. For patient aged 80 and over the transfer rate fell to 32%. Even when adjusting for proximity from tertiary-level trauma centres, older patients have still been shown to face significant levels of undertriage. This was demonstrated in a retrospective cohort study looking at 10 years of statewide registry data from Oklahoma, USA where patients aged over 55 where significantly less likely to be taken to a tertiary-level trauma centre either from the scene of injury or via hospital transfer (86). These findings may go some way to explaining why a review examining the impact of successive NICE Head Injury Guidelines from 2003 to 2014 demonstrated no improvements in TBI mortality rates for over 65s, contrary to the findings in younger ages groups (87). The 2007 guidelines, which pre-date the existence of trauma systems in the UK, recommended that patients with severe TBI should be managed in specialist neuroscience centres.

Initial neurological presentation may differ in older patients and have a direct influence on triage decisions. In common with other studies (8, 17), our elderly patients had a higher initial GCS which may have led to initial TU triage. The pattern of TBI pathology found in our study may further explain this observation given that there were a higher proportion of isolated subdural haematomas in the elderly transferred group which may have presented with a slower neurological deterioration than other intracranial pathologies. Increased age, frailty and comorbidities may also preclude the primary triage of elderly TBI patients to neurospecialist care due to the anticipated futility of intervention(88). Transferred patients across all ages were more likely to undergo surgical evacuation of an intracranial haematoma, however, more elderly patients who were safely transferred for neurospecialist care survived despite comparable injury severity with those older patients taken directly to an MTC. In a retrospective study of almost 54000 TBI patients from the US National Trauma Databank, Sugerman et al performed a similar multivariate analysis of outcomes between direct admissions to Level I/II trauma centres (MTC-equivalent) and secondary transfers. In their study the transferred patients were seen to have a lower mortality (28% vs 32%) and in the multivariate analysis transfers were associated with a 21% lower odds of death (74). Unlike in our study there was no analysis of outcomes in patients taken to TU-level care, which could skew results or lead to a survivor bias. Furthermore, injury severity was also a significant predictor of mortality which was not the case in our study. Whilst there were a higher proportion of brainstem injuries and DAI in our NSC-DIRECT group, it may not be differences in TBI pathology or neurosurgical intervention alone that explain the mortality difference. For the NSC-DIRECT cohort, earlier involvement of geriatric physicians in the management of elderly MTC patients in areas such as anticoagulation management or early intervention prognostication may be warranted as set out in ‘silver trauma’ guidelines such as the British Geriatric Society’s Silver Book (84,89–91).

MTC admission among neurospecialist patients conferred no home discharge benefit compared to those transferred for neurospecialist care. For conservatively treated MTC patients there was a greater likelihood of home discharge, which may reflect the increased provision of early inpatient rehabilitation and physical therapies at these institutions (92). Within this cohort of CONS-MTC patients, the difference in discharge outcomes cannot be explained by infrastructure provision such as access to neurosurgery or neurospecialist care. Therefore, further investigation is required to identify predictors of improved outcome in conservative patients, such as clinician education, rehabilitation therapy provision and access to community recovery resources. Patients admitted to TUs with neurosurgical capability were excluded from this study, however a recent similar US study did include such patients and still demonstrated superior rates of home discharge in patients admitted directly to MTC-level care (93). Lengths of stay were longer for both directly admitted neurospecialist care and conservatively managed MTC patients. This confirms findings in previous studies showing longer lengths of stay for Level I trauma patients which may be due to higher intensity of care as well as difficulty accessing post-discharge care in the more built up urban areas that MTCs tend to be in where there may be more social deprivation (22).

Given the largely insignificant impact of primary MTC admission on mortality overall, it may be appropriate to triage a greater number of isolated TBI patients to TUs, provided rapid transfer to an MTC can be undertaken should the need arise. The decision to transport to a TU can effectively be seen as allowing a second stage of triage to take place within the receiving TU’s Emergency Department with the added benefit of diagnostic imaging, initial stabilisation, and further clinical expertise prior to making an informed decision to transfer to an MTC. In rural or more remote settings, TUs or equivalent non-specialist acute hospitals may play a key role in stabilising patients with long transport times to the nearest MTC(94). An initial ‘pit-stop’ at a TU could ensure that at the very least a secure definitive airway is in place and oxygen delivery is maximised through appropriate ventilation strategies and management of hypotension in order to reduce the risk of secondary hypoxic brain injury (95). Drug-facilitated intubation by prehospital physicians reduces the incidence of patients arriving to hospital hypoxic (96) and largely removes the need to stop at TUs en-route to an MTC. Previous retrospective studies have reflected our study's findings that interhospital transfer within an organised trauma system is not significantly associated with worse outcomes and furthermore may provide an opportunity for greater TU engagement in the trauma system whilst protecting MTCs from being overburdened (74,94,97,98). A recent UK pilot prospective cluster randomised controlled trial compared bypass of TBI patients to specialist neuroscience centres against transport to the nearest non-specialist acute hospital and showed similar 30-day mortality of 9% in the two trial arms with similar demographics and injury characteristics (72).

From our cohort of TBI patients it appears that the LMTS triage tool works well in recognising many of the most urgent cases: those requiring intubation and direct transfer for neurosurgical intervention. However, just under half of all patients requiring neurospecialist intervention were primarily taken to a trauma unit, although this was not associated with increased mortality outcomes. Split among the age groups, 38% of adult patients requiring surgery had to be transferred to MTCs compared to 64% in the elderly group. Under-triage in elderly patients is a recognised concern nationally (85), and Sharma et al in their retrospective cohort study of over 9400 patients demonstrated a stepwise reduction in access to specialist trauma centre care with advancing age(99). Crucially the Sharma study did not include GCS as variable in the statistical analysis and was a study set in the Canadian province of Ontario where journey times may have played a significant role in determining hospital destination. Nonetheless it still demonstrates the variability in access to specialist TBI care for older patients. In our study, as well as being younger, the MTC patients had a lower admission GCS than TU patients. Despite this, median ISS scores were remarkably similar between the triage groups in patients receiving neurospecialist care. This corroborates findings made by previous authors showing that GCS scores in the elderly may not correlate with the severity of brain injury as well as they do in younger patients and may lead to an underestimation of the severity of injury (100). Geriatric-specific triage tools with altered physiological parameters have been shown to increase sensitivity with an unwelcome increase in rates of overtriage and only small improvements in patient outcome (101−103). A recent and comprehensive systematic review of prehospital elderly triage studies involving 1.3 million patient records identified a developing consensus regarding the inclusion of higher thresholds for physiological parameters, namely SBP and GCS in this patient cohort, however variability between studies in terms of age cut-off and triage criteria still limit the strength of conclusions that can be drawn (104).

Robust secondary transfer protocols should facilitate the expedited transfer of deteriorating or under-triaged patients from TUs to MTCs, and allow for greater TU engagement within an inclusive system (74,97,98,105). Our findings suggest that the LMTS transfer policies result in safe processes that are not associated with increased mortality for TBI patients requiring neurospecialist care. Further, care closer to home for specific patient groups such as the elderly, may be beneficial in enabling local family, primary and social care support.

Physicians working outside of MTCs report a lack of confidence in performing emergency trauma procedures and performing the role of Trauma Team Leader (106), a concern previously shared by various stakeholders during the setup of regionalised trauma systems(107). Whilst specialty trainees on clinical rotations can expect to spend a period of time working at an MTC, permanent staff at TUs such as consultants, staff grades, nursing and theatre staff may not be afforded such opportunity. This lack of trauma exposure can only be mitigated to some degree through MTC-led regional education and training. A manageable and steady caseload of severely injured patients is required to maintain and sharpen clinical acumen, departmental processes and the technical expertise required for the safe management of such patients. This is especially important given that TUs have in recent years been called upon to provide such care as part of Major Incident responses to mass casualty events in London and around the UK.

3.4.1 Limitations and Strengths

This study is limited by the inherent problems associated with retrospective and observational registry studies such as the inability to demonstrate causality. The TARN database is populated by clerical staff who receive specific training for TARN entry but rarely come from a clinical background, therefore there may be a number of cases in which data is entered erroneously or misclassified leading to information bias. Furthermore there may have been selection bias due to longstanding problems with incomplete TU TARN submissions. There were a small number of patients with missing GCS data (6% of NSC patients and 4% of analysed CONS patients) and although these patients were not excluded overall, it may have had a small impact on median GCS calculations. In the regression modelling SPSS would have excluded these cases from analysis. Multivariable regression analysis may not account for all the differences between the age and treatment groups thus limiting internal validity; and residual confounding may result from unmeasured, unknown or misclassified confounders. Prehospital vital signs such as heart rate and blood pressure would have been useful predictor variables for consideration in the regression models were they available. Further measures of patient co-morbidity such as the Charlson Comorbidity Index would have also been helpful for the regression models, however this is not a part of the data collected by TARN. There was no recording of Glasgow Outcome Scale or other measure of long-term outcome. Home discharge was used as a surrogate, but this may be affected by access to other services such as rehabilitation centres or nursing homes. Hospital length of stay may have been influenced by intended discharge destination (i.e. clinically stable patients awaiting rehabilitation facility placement).

Overall, this was a large study of 6200 patients with isolated severe TBI. There are many studies comparing outcomes of direct admission and transfers in trauma patients, however few have examined outcomes of those with TBI remaining at TUs or non-specialist trauma hospitals. As far as we are aware, none have directly compared outcomes of TBI patients receiving conservative care at MTCs and TUs (or their equivalents). Analysis of the 642 excluded conservatively-treated transfer patients and the reasons for their transfer may shed further light on the flow of patients around the trauma system and help identify areas for improving system efficiency.

3.4.2 Generalisability

The results of this study may be reflective of findings in other similarly sized developed urban trauma systems around the UK. In the LMTS, no TU is realistically more than an hour away from it's receiving MTC by road on 'blue lights' or otherwise. In more rural or sprawling urban settings journey times from TU to MTC may be considerably longer and in some cases require the use of fixed wing or rotary aircraft with specialist medical teams onboard. This may add a layer of complexity and excessive delay to hospital transfers meaning undertriage may be less well tolerated in these settings.

3.5 Conclusion

Within our inclusive trauma system patients requiring secondary transfer for neurospecialist care did not experience worse outcomes than those admitted directly to an MTC. Few differences were seen between conservatively managed patient groups in differing levels of care. Our study suggests that within this isolated TBI population it may be safe and beneficial from a system-level perspective to manage greater numbers of patients at Trauma Units provided robust transfer protocols are in place. Future prospective work is required to assess the effectiveness of existing trauma triage tools and the impact of age and triage decisions on outcomes.

Chapter 4: STUDY 2: Exploring the association between prehospital triage and outcomes (TuTOR Study)

4.1 Introduction

The previous chapter highlights the level of overtriage often associated with inclusive urban trauma systems. From a TBI population of 6199 patients only 12% required a neurocritical intervention yet 37% were triaged directly to an MTC with some 10% of patients being secondarily transferred from a TU and still not requiring a neurocritical intervention. It also demonstrates the nuanced role that age may play in trauma outcomes. Importantly, the previous chapter has shown that there is a potential for safely relieving MTC burden and increasing trauma system inclusivity whilst keeping more patient at their local hospital within their local community. Although these findings focused on isolated traumatic brain injury, they naturally prompt further assessment of the triage tool in its entirety.

Patients who require time-critical care from specialist services have improved outcomes when primarily transferred to a regional MTC (11,14,17,22). The prehospital identification of severely injured patients who will benefit from specialist trauma centres can be challenging, but the potential consequences of missed life-threatening injuries are large (14,26,35). Conversely, overtriage at MTCs may lead to capacity issues, impacting on elective treatment pathways (108) and critical care bed utilisation (109). Prehospital triage tools therefore underpin the performance, effectiveness, and sustainability of a regional trauma system. The optimal criteria for a prehospital tool, to effectively balance both trauma patient outcomes and resource utilisation within an inclusive trauma system, are not known and will to some extent be influenced by geographic, logistical, and political factors unique to each trauma system. The a key stage in developing optimal triage criteria would be to link prehospital triage decisions with in-hospital outcomes in order to show which triage criteria identify patients/injuries requiring primary MTC triage, versus those who can be managed with initial TU assessment even if they later require transfer to an MTC.

Within the London trauma system there is no structure in place to link prehospital data to in-hospital data to help facilitate the understanding of which components of the London triage tool are associated with access to care and how these impact on patient outcomes.

Information about clinical care and outcomes for trauma patients in London is derived from two separate registries. Clinical prehospital data are entered into the London Ambulance Service (LAS) registry and used to audit performance measures such as scene times and conveyance destinations. In a separate system, all MTCs and TUs submit in-hospital trauma data to the national Trauma Audit Research Network (TARN) registry- detailed in Chapter 2.4.1. The TARN registry holds clinical information including mortality, intensive care (ICU) use, injury severity score (ISS) and discharge destination. By matching these datasets, I hoped to be able to highlight which components of the triage tool optimally identify severe injuries and best determine the level of care required.

The overall aim of this study was to explore the relationship between prehospital triage decisions and patient outcomes in the context of an urban inclusive trauma system. Specific objectives were:

- To identify which aspects of the London trauma triage tool best identify patients with traumatic injuries which required urgent surgical/radiological interventions

- To explore the relationship between prehospital trauma triage decisions, mortality, and discharge outcomes at major trauma centres.

- To specifically assess the performance of the existing age cut-off for direct triage to MTC (age >55 years)

A retrospective study was conducted of all trauma patients activating the existing London triage tool within a 12-month period across this urban inclusive trauma system.

4.2 Methods

4.2.1 Setting and participants

The setting of this study was the London Major Trauma System (LMTS) which has been described in detail in Chapter 1.2.6. This study was originally conceived as a collaborative retrospective observational registry study between the Centre For Trauma Sciences (Queen Mary University of London) and the London Ambulance Service. The study was given the title Trauma Triage and Outcomes Research (TuTOR) and the stated aim was to investigate how prehospital triage decisions affect resource use and trauma patient outcomes in order to minimise variation in access to care. I helped to draft the protocol, organise internal peer review and applied for Health Research Authority (HRA) approval via the Integrated Research Application System (IRAS) online platform. The TuTOR study protocol was reviewed by the HRA (reference 18/HRA/0399)) and the need for Research Ethics Committee approval was waived. Further detail on the ethics and approvals process for TuTOR can be found in Chapter 2.3.

The LAS is the single ambulance service for the Greater London geographic area. At the time of study conception, they maintained an independent database/registry of trauma patients attended to by the service which was used to used to audit performance measures such as scene times and conveyance destinations. Paper patient report forms (PRFs) were completed by each ambulance crew following a patient attendance. These PRFs were given to the receiving Emergency Department staff as part of the initial patient handover and a carbon copy retained by the ambulance crews. These PRF copies were manually scanned onto LAS computer systems and relevant data manually extracted from closed fields and free text boxes on the PRFs to populate their trauma registry. This was carried out manually by a member of the LAS Clinical Audit and Research Unit (CARU). The data was stored on a password-protected Microsoft Access® database accessible to CARU staff, who were able to extract the data to a Microsoft Excel® spreadsheet to facilitate data linkage (see 4.2.3 below).

During the study period the LAS was using the bespoke London Major Trauma Decision triage tool shown in Fig. 1.4. to determine the destination of injured patients. This triage tool is divided into five 'Steps" which sequentially assess a patient's physiology, anatomical injuries, mechanism of injury and any special concerns. There is also provision to allow patients to be triaged to an MTC based on the discretion of the attending crew (Crew Concern) irrespective of whether the patient meets the previous four criteria. Patients who trigger on one of the steps of the tool are defined as triage positive and transported directly to the nearest MTC, bypassing all other local hospitals. MTCs also act as TUs for patients in their local catchment area. These patients will therefore be taken to their local MTC even if they do not trigger the triage tool (triage-negative). These patients were not included in the triage-positive patient data obtained from TARN. The relative lack of LAS registry data pertaining to triage-negative TU patients plus time constraints meant a decision was taken to confine the study to triage-positive MTC patients

De-identified data for all adult trauma patients (16 years and above) defined as triage-positive and transported to a hospital within LMTS in 2016 was requested from TARN. Patients were deemed to be triage-positive if they triggered one of the steps on the triage tool. Exclusion criteria were patients not attended to by the London Ambulance service, or duplicated entries where for example two or more prehospital services attended the same patient. At the time of commencing the study, 2016 was the most recent year with a full set of TARN data available. It was agreed during departmental meetings that 1 year of data would provide a suitable number of subjects for the study, taking into account time constraints and the need to match the data between databases.

4.2.2 Variables

This was a retrospective study of prospectively collected clinical data, matching patient information held in two databases − the LAS prehospital trauma database and the TARN registry. The LAS prehospital dataset contained information on the criteria used for the triage decisions whilst TARN recorded outcome data pertinent to the aims of this study.

Data was extracted for age, gender, mechanism of injury, date and time of hospital arrival, CAD (Computer-Aided Dispatch) number, in-hospital treatments, injury severity, 30-day mortality, discharge destination and lengths of stay. The CAD number is a numerical identifier assigned to a prehospital event by emergency services (police, fire, ambulance, and other emergency services). The CAD is unique for a given 24-hour period. CAD numbers may be reused on a separate day, therefore the CAD number can only function as a unique identifier if given alongside the date of the incident.

Outcome measures were 30-day mortality rates and rates of home discharge. A further process measure of interest was rates of early surgical or interventional radiological intervention. Further details of these outcome measures are outlined in Chapter 2.6.

Long-term outcome measures such as the Glasgow Outcome Scale were not consistently captured by TARN and therefore home discharge was used as a surrogate measure of functional recovery (See Chapter 2.5).

4.2.3 Data Linkage

De-identified TARN data was matched deterministically with LAS prehospital trauma registry data on-site at the LAS CARU unit, Pocock Street, London SE1 0BW. Definitive matches were made using the incident date and CAD number as these were fields common to both the LAS and TARN registries. A pragmatic approach was adopted to allow for human error in data entry, therefore a 'strong match' was determined as those cases where the CAD was missing/invalid, but where all other variables matched (date and time of incident, age, gender, mechanism of injury). Only 'definitive matches' and 'strong matches' were included for analysis.

A CAD reference is incident-specific rather than patient-specific and is used between all responding emergency services. For example, a road traffic collision (RTC) involving multiple casualties with a multi-agency response (Police, Fire and Ambulance Services) would have the same CAD assigned to all patients from that incident. Not all patients from a given incident are conveyed to the same hospital. Each patient is triaged individually to the appropriate level of care. Extra care was taken during the matching process to ensure that even where a strong match was obtained, that patient demographics still matched and injury patterns were seen to be consistent with injury mechanisms to ensure the correct patient from the LAS registry was chosen to match the corresponding TARN record. For example, 2 patients with the same date-CAD identifier from an RTC but one was a 19 year old female and the other was a 23 year old male could easily be matched to the appropriate TARN records based on the demographics. Further background on the database linkage process is given in Chapter 2.3.3.

To assess the performance of the age criteria in the penultimate step of the triage tool (Step 4A: age> 55 years), comparisons were made between patients triggering Step 4A who were admitted directly to an MTC, with triage-negative patients aged over 55 year who were managed exclusively in Trauma Units. Analysis was also performed within a sub-cohort of patients aged 70 years and over, as this was the age threshold used to identify older patients within the LMTS Elderly Trauma guidelines(84). This direct MTC to TU comparison was performed for Step 4A alone because age as a triage criterion was readily available in both the prehospital and TARN data, whereas information required to trigger the other triage steps (i.e. prehospital physiology or suspected injuries) was not available on TARN. For example, it would not have been possible to compare MTC patients with a prehospital systolic blood pressure of <90mmHg (Step 1B) with a cohort of TU patients found to have had a prehospital systolic blood pressure of <90 as this level of prehospital TARN data was not available for TU patients.

4.2.4 Bias

To improve the accuracy and efficiency of data collection in the absence of suitable matching software and thus minimize information bias, two investigators (myself and student paramedic Imogen Gunson- see Acknowledgments, page v) deterministically matched TARN and LAS patient records using the approach described above. Any uncertainties concerning the strength of a match between database were discussed and resolved contemporaneously.

4.2.5 Data analysis

Continuous data were assessed for normal distribution with the Shapiro-Wilk test in IBM SPSS Statistics version 25. Descriptive statistics were performed using Graphpad Prism version 7. All continuous data was judged to be non-parametric and therefore analysed using Graphpad Prism with Dunn's tests used for individual post-hoc comparisons between triage groups. Individual comparisons of categorical data (for example, 30-day mortality or home discharge rates between triage steps) were performed using Fisher exact tests for proportions. For the comparison of elderly triage-positive and triage-negative patients multivariable regression models analysed statistically independent relationships between the dependent variables (30-day mortality, early intervention and length of stay) and other explanatory variables pertaining to patient factors (i.e. age and GCS) and levels of care (MTC vs TU). Variables achieving significance of p<0.1 in univariate analysis were entered into the regression models. Multivariate linear regression was used to analyse the continuous dependent variable of hospital length of stay and binary logistic regression for the categorical dependent variables (30-day mortality and early intervention). Results of logistic regression were reported as odds ratios (OR) with 95% confidence intervals whilst linear regression was reported as B coefficients with 95% confidence intervals. All multivariable regression analysis was performed in SPSS. Hosmer-Lemeshow tests and Nagelkerke R squared values are reported for each regression model beneath the respective tables. A further explanation of these measures and their implication for model interpretation is provided in Chapter 2.4 (Statistical Methods).

4.3 Results

A total of 2650 triage-positive TARN entries from 1st January to 31st December 2016 were reviewed for this study. Nine hundred and eleven entries were initially excluded. From these excluded patients, 572 were from surrounding counties transferred into London by other non -LAS ambulance services and were therefore unmatchable, 123 patients were under 16 years and 216 were attended to by more than one prehospital provider resulting in duplicate entries. Of the remaining 1739 patients, 1217 (70%) were definitively or strongly matched to a TARN record. A further 47 matched patients triaged to an MTC based on prehospital physician override of the triage tool were excluded, leaving 1170 patients with full prehospital and in-hospital data for further analysis (Fig. 4.1).

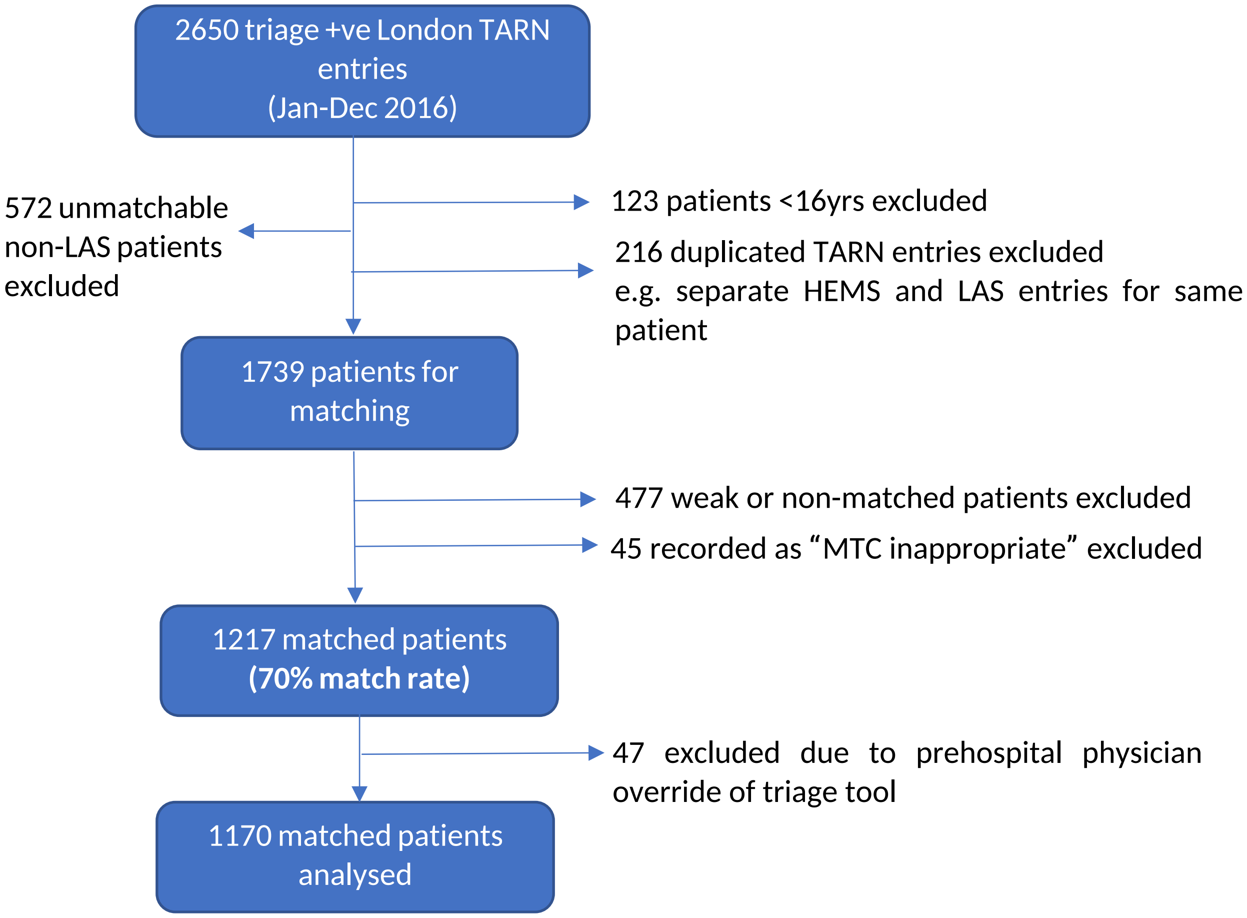


Figure 4.1: Selection and exclusion criteria

Four hundred and eight (35%) of the 1170 triage positive patients triggered the tool on Step 1 (critical alterations in physiology). Five hundred and thirty-nine patients (46%) triggered on Step 2 (anatomical injuries), and 89 (7.6%) on Step 3 (mechanism of injury). One hundred and fifteen patients (9.8%) triggered only on Step 4 criteria (special considerations), most of which (101 patients - 88% of Step 4 total) triggered as they were aged over 55 years. Nineteen patients were triage positive because of an ambulance crew concern not captured within Steps 1-4 (Table 4.1). GCS data was missing from 8 patients. Ironically 7 of those were patients triaged on step 1A (GCS 13 or less) indicating perhaps an oversight in entering data for a clearly unconscious patient and 1 patient had been triaged on step 4A(age >55). Three patients lacked any discharge information (all Step 2). No other missing data was noted from the main TuTOR cohort.

	STEP 1 (Physiology)	**STEP 2 (Anatomy)**	**STEP 3 (Mechanism)**	**STEP 4 (Special)**	**STEP 5 (Crew concern)**
Data are presented as ≠n (%) or †median (IQR)					
n (%)	408 (35)	539 (46)	89 (8)	115 (10)	19 (2)
Age (years) †	42 (28-64)	42 (26-58)	37 (26-52)	76 (68-84)	41 (27-55)
Male≠	308 (75)	407 (76)	69 (78)	72 (63)	16 (84)
GCS†	11 (6-14)	15 (15-15)	15 (15-15)	15 (14-15)	15 (14-15)
Pre-hospital intubation≠	155 (38)	18 (3)	2 (2)	0 (0)	0 (0)
ISS†	25 (16-34)	10 (9-20)	16 (9-24)	14 (9-21)	13 (9-17)
ISS>15≠	331 (81)	214 (40)	45 (51)	57 (50)	8 (42)
Early Intervention (%)≠	118 (29)	133 (25)	8 (9)	2 (2)	2 (11)
Critical care admission≠	254 (62)	107 (20)	10 (11)	10 (9)	1 (5)
Critical care LOS (days) †	7 (3-16)	3 (1-7)	4 (1-8)	2 (1-6)	2 (2-2)
30-day mortality≠	75 (18)	11 (2%)	0 (0)	6 (5)	0 (0)
Hospital LOS (days) †	18 (8-40)	10 (5-18)	11 (5-21)	11 (7-21)	6 (3-7)
Home discharge≠	209 (63)	431 (82)	72 (81)	84 (77)	14 (74)

Table 4.1: Patient demographics, injury and outcomes per triage groups

GCS= Glasgow Coma Scale, ISS= Injury Severity Score, LOS= Length of stay. All continuous variables (Age, GCS, ISS) differ significantly overall between triage groups (Kruskal-Wallis p<0.05). Discharge destination and lengths of stay given for survivors only

Forty four percent of all triage-positive patients managed at an MTC were not severely injured (ISS<15). Over three quarters of patients (77.5%) did not undergo early intervention and less than one third (32.6%) were admitted to critical care. Total cohort mortality was 8%. Among survivors 75% were discharged home and 29% stayed less than seven days in hospital. Overall, 534 (46%) of patients survived and were discharged home without the need for early intervention or critical care admission.

Amongst Step 1 patients, the majority (81%) were severely injured, comprising 51% of all 655 patients in the study with an ISS >15. Step 1 patients also had the highest median ISS of 25 (IQR 16-34) (Table 4.1, Fig. 4.2). One hundred and eighteen (29%) required a surgical intervention within 12 hours of hospital admission (Fig. 4.3), the majority being urgent neurosurgical procedures (38% of Step 1 cases), followed by abdominal surgery (25%) and limb or pelvic procedures at 14% (orthopedic, vascular and/or plastic surgery procedures) (Fig. 4.4).

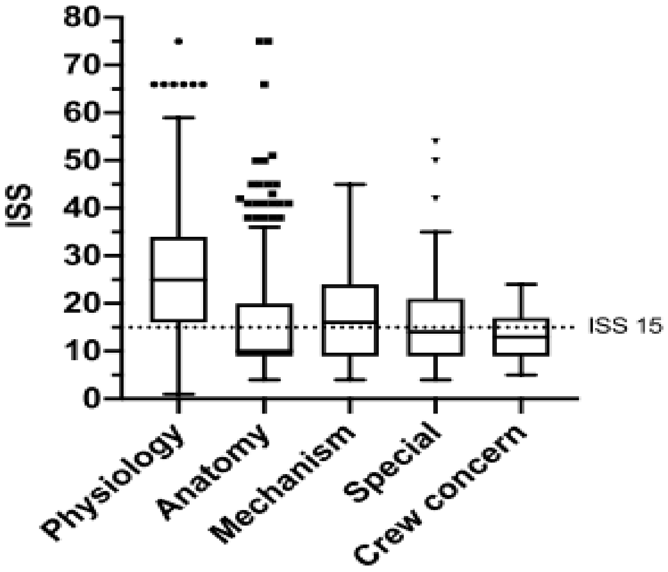


Figure 4.2: Median Injury Severity Scores with interquartile range (all triage steps)

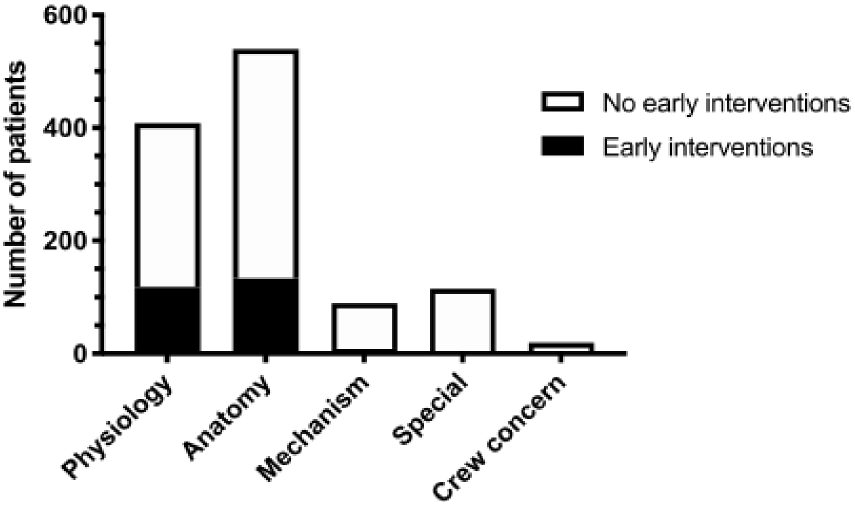


Figure 4.3:Numbers within each step undergoing early intervention (all triage steps)

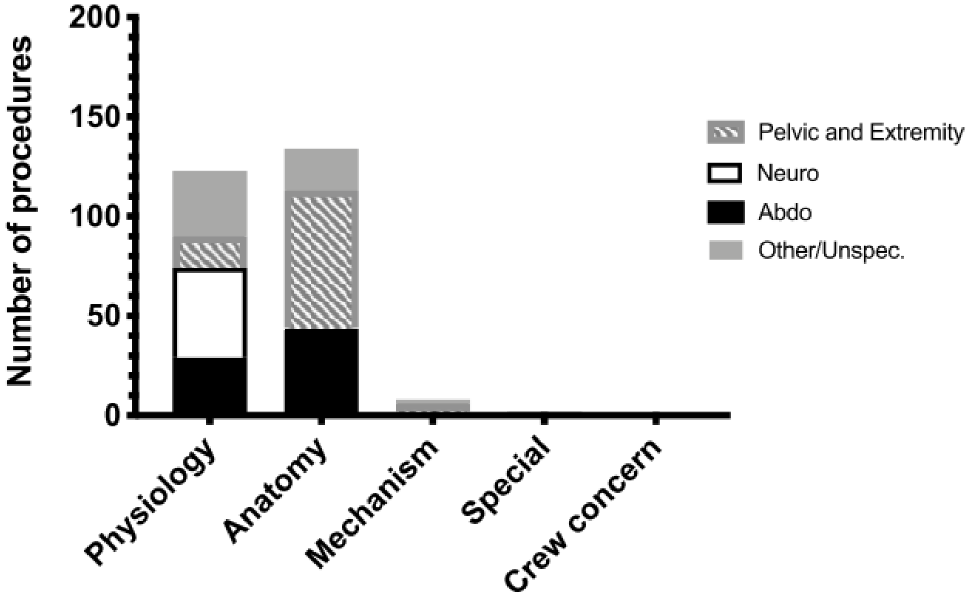


Figure 4.4: Types of surgical intervention

Sixty-two percent of Step 1 patients were admitted to critical care. Thirty-day mortality was highest in Step 1 patients (Fig. 4.5), and 82% of all deaths were in patients triaged by Step 1. Total hospital length of stay was also significantly longer for Step 1 patients than for patients in Steps 2-5, and fewer patients who triggered Step 1 were discharged to their own home compared to all other patients combined (63% vs 81%, $p<0.01$) (Fig. 4.6).

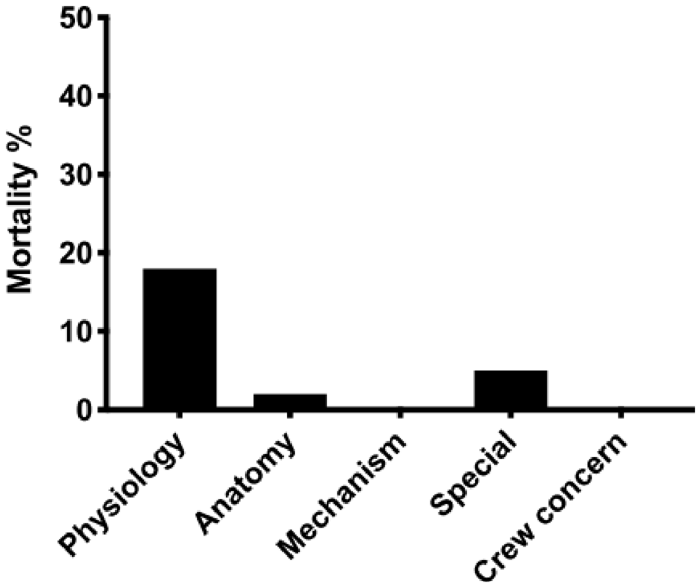


Figure 4.5: 30-day mortality (all triage steps)

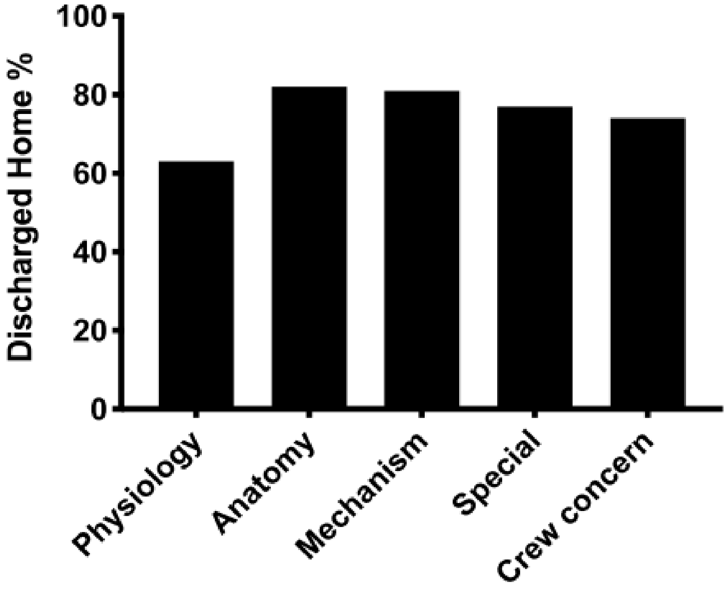


Figure 4.6: Survivor home discharge (all triage steps)

Patients triaged by Step 2 were the largest category, representing 46% of the whole cohort. Median ISS of Step 2 patients was 10 (IQR 9-20) and 25% received an early intervention. Twenty percent of patients were admitted to critical care, but mortality was very low at 2% and 82% of patients were discharged to their own home.

The performance of the individual criteria in Step 2 were explored in further detail (Table 4.2). No patients were triaged due to sustaining circumferential burns (2J on the triage tool- not included in results table). The largest cohorts were those with a suspected pelvic fracture (Step 2E - 29% of Step 2 patients); open fractures (Step 2G: 20%); penetrating torso trauma (Step 2C: 20%) and chest injuries (Step 2A: 14%) (Figure 4.7). Early interventions were also concentrated in these categories (Fig. 4.8). Penetrating torso trauma patients (2C) had the highest number of early interventions, the majority of which (66%) were laparotomies followed by extremity procedures (19%). Extremity or pelvic orthopedic procedures made up the majority of all other Step 2 interventions (68% of non-Step 2C early interventions). Early surgery was only required in 15% of the 157 suspected pelvic fracture (2E) patients. The majority of surgical procedures in 2E patients were limb procedures, with no patients undergoing urgent pelvic fixation and only four patients requiring early angioembolization. A breakdown of injuries in 2E patients is listed in Appendix 1. No patient in Steps 2D (suspected skull fracture) or 2F (suspected spinal trauma with abnormal neurology) had a neurosurgical intervention within the first 12 hours of admission (Fig. 4.9). Mortality was low across the cohort, with only one death in the Step 2C patients with penetrating trauma. Three of the 40 patients with suspected spinal cord injury died, and these patients also had the lowest rate of home discharge at 62%.

Step 2 triggers	**2A**	**2B**	**2C**	**2D**	**2E**	**2F**	**2G**	**2H**
Data are presented as $^{\neq}$n (%) or †median (IQR)								
n	73	7	108	45	157	40	108	1
Age (years) †	45 (26-61)	41 (18-64)	25 (19-40)	48 (31-69)	44 (32-58)	57 (33-67)	43 (29-60)	25
Male$^{\neq}$	64 (88%)	5 (71)	97 (90)	30 (67)	111 (71)	25 (63)	74 (69)	1 (100)
GCS†	15 (15-15)	15 (15-15)	15 (15-15)	15 (14-15)	15 (15-15)	15 (14-15)	15 (15-15)	15
Pre-hospital intubation$^{\neq}$	8 (11%)	2 (29)	1 (1)	1 (2)	3 (2)	0 (0)	2 (2)	1 (100)
ISS†	18 (10-25)	9 (9-14)	9 (9-16)	18 (13-26)	13 (9-25)	15 (9-25)	9 (9-10)	50
ISS>15$^{\neq}$	45 (62%)	1 (14)	27 (25)	33 (73)	70 (45)	20 (50)	17 (16)	1 (100)
Early Intervention (%)$^{\neq}$	19 (26)	6 (86)	47 (44)	3 (7)	23 (15)	1 (3)	34 (31)	0 (0)
Critical care admission$^{\neq}$	28 (38%)	3 (43)	29 (25)	7 (16)	26 (17)	4 (10)	10 (9)	0 (0)
Critical care LOS (days) †	3 (1-8)	2 (1-34)	2 (1-3)	3 (1-13)	6 (2-11)	18 (5-63)	1 (1-6)	n/a
30-day mortality$^{\neq}$	2 (3%)	0 (0)	1 (1)	2 (4)	1 (0.6)	3 (8)	2 (2)	0 (0)
Hospital LOS (days) †	9 (6-13)	20 (12-61)	6 (4-10)	8 (5-20)	13 (7-23)	12 (7-20)	12 (6-18)	1
Home discharge$^{\neq}$	56 (79%)	5 (71)	97 (91)	35 (81)	127 (81)	23 (62)	88 (83)	0 (0)

Table 4.2: Step 2 demographics, injury and outcome data

2A: Chest injury with altered physiology **2B:** Traumatic amputation/mangled extremity proximal to wrist/ankle **2C:** Penetrating trauma below the head above the knees (not arms) **2D:** Suspected open and/or depressed skull fracture **2E:** Suspected pelvic fracture **2F:** Spinal trauma suggested by abnormal neurology **2G:** Open fracture of the lower limb proximal to the ankle **2H:** Burns/scald >30% BSA. GCS= Glasgow Coma Scale, ISS= Injury Severity Score, LOS=Length of Stay. Discharge destination and lengths of stay given for survivors only.

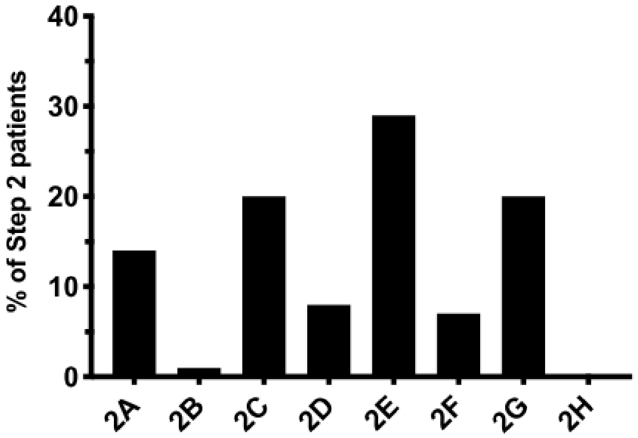


Figure 4.7: Percentage of Step 2 patients within each Step 2 trigger

2A: Chest injury with altered physiology **2B:** Traumatic amputation/mangled extremity proximal to wrist/ankle **2C:** Penetrating trauma below the head above the knees (not arms) **2D:** Suspected open and/or depressed skull fracture **2E:** Suspected pelvic fracture **2F:** Spinal trauma suggested by abnormal neurology **2G:** Open fracture of the lower limb proximal to the ankle **2H:** Burns/scald >30% BSA.

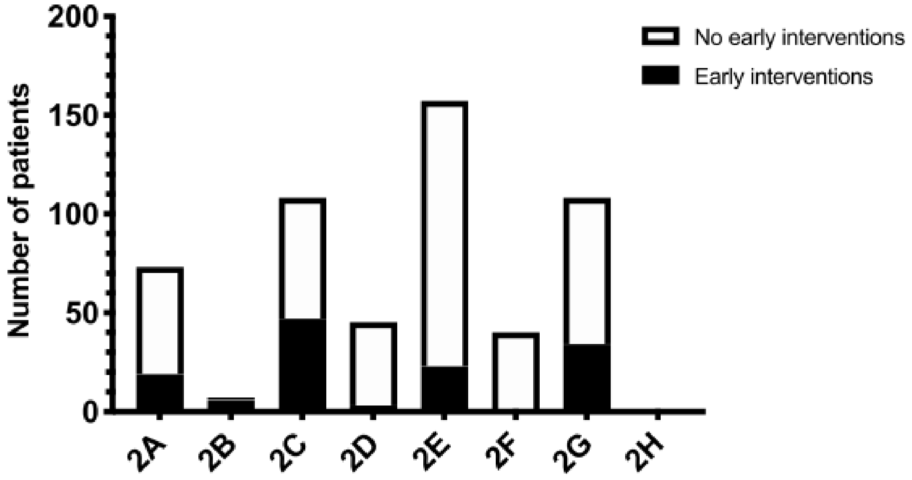


Figure 4.8: Numbers within each Step 2 trigger undergoing early interventions within 12 hours of admission

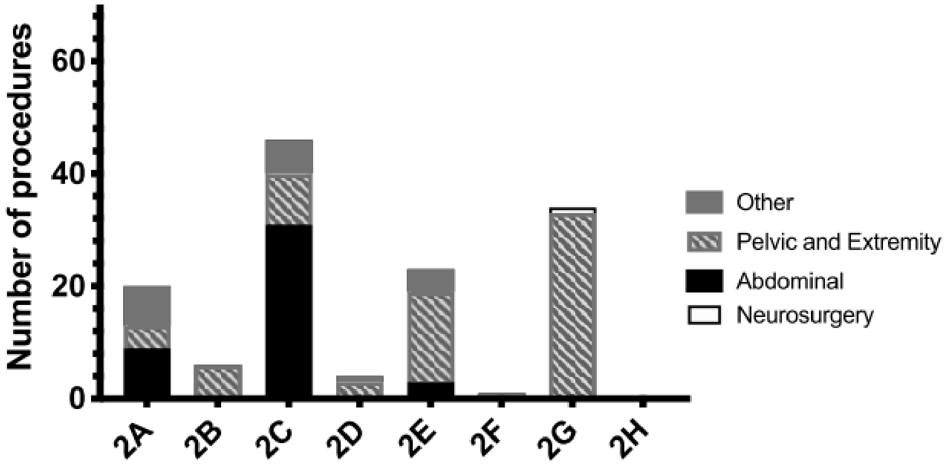


Figure 4.9: Types of surgical intervention within each Step 2 trigger

2A: Chest injury with altered physiology **2B:** Traumatic amputation/mangled extremity proximal to wrist/ankle **2C:** Penetrating trauma below the head above the knees (not arms) **2D:** Suspected open and/or depressed skull fracture **2E:** Suspected pelvic fracture **2F:** Spinal trauma suggested by abnormal neurology **2G:** Open fracture of the lower limb proximal to the ankle **2H:** Burns/scald >30% BSA.

Of the 89 patients triggering the triage tool based on mechanism of injury only (Step 3), 51% were severely injured with an ISS of >15 and 11% were admitted to critical care. However only eight (9%) of these patients received an early intervention and none of these involved major neurological, abdominal, pelvic or extremity surgery. There were no deaths in this group and 77% of patients were discharged home.

In Step 4 (special concerns), 101 of the 115 patients were aged over 55 years (88% - Step 4A). This group is examined in further detail below. One pregnant patient (Step 4B) had a GCS of <14 and was therefore triaged according to Step 1 based on the hierarchical nature of the triage tool. Thirteen patients were on anticoagulant medication (Step 4C) and one patient was morbidly obese (Step 4D). Step 4C patients had a median ISS of 14 (IQR 9-21), none required urgent surgical intervention and there was a single mortality.

Comparisons were made between the 101 older patients (>55 years) who triggered on Step 4A and 6430 patients aged over 55 who were managed in Trauma Units (non-triage positive) over the same period. Overall, MTC patients were younger (median age 75 v 81 years, p<0.01) and more severely injured (median ISS 14 v 9, p<0.01) than their TU equivalents (Table 4.3). However, there were no statistically significant differences between older patients admitted to MTC via Step 4A or those managed in TUs in rates of early surgery (2% in both groups), 30-day mortality (MTC 4A vs TU: 5% v 7%, p=0.69), or home discharge (MTC 4A vs TU: 75% vs 65%, p=0.05). Older patients were more likely to be discharged directly to a nursing home from TUs, and this difference was concentrated in patients aged 70 years and above (nursing home discharge MTC 4A vs TU: 5% vs 13%). GCS data was missing for 338 out of the 6340 TU patients. No other missing data from the variables of interest were noted.

	All patients aged >55		**Patients aged 56-69**		**Patients aged 70+**	
Data are presented as ≠n (%) or 'median (IQR).	**MTC (4A)**	**TU**	**MTC (4A)**	**TU**	**MTC (4A)**	**TU**
n	**101**	**6430**	**31**	**1436**	**70**	**4994**
Age (years) '	75 (68-84)	81 (71-88)*	63 (58-67)	62 (59-65)	81 (75-86)	85 (79-90)*
Male≠	65 (65%)	2505 (39%)*	20 (65%)	714 (50%)	45 (64%)	1791 (36%)*
GCS'	15 (14-15)	15 (15-15)*	15 (14-15)	15 (15-15)*	15 (14-15)	15 (15-15)
Pre-hospital intubation≠	0 (0%)	8 (0.1%)	0 (0%)	4 (0.3%)	0 (0%)	4 (0.1%)
ISS'	14 (9-22)	9 (8-16)*	13 (9-25)	9 (9-13)*	16 (9-21)	9 (8-16)*
ISS>15≠	50 (50%)	1796 (28%)*	14 (45%)	300 (12%)*	36 (51%)	1496 (30%)*
Early Intervention (%)≠	2 (2%)	151 (2%)	0 (0%)	55 (4%)	2 (3%)	96 (2%)
Critical care admission≠	10 (10%)	237 (4%)*	3 (10%)	86 (6%)	7 (10%)	151 (3%)*
Critical care LOS (days) '	2 (1-6)	3 (1-6)	7 (1-13%)	3 (1-7)	2 (1-3)	3 (2-6)
30-day mortality≠	5 (5%)	435 (7%)	0 (0%)	24 (2%)	5 (7%)	411 (8%)
Hospital LOS (days)'	11 (6-22)	11 (6-20)	8 (5-17)	4 (8-14)	13 (8-25)	12 (6-22)
Home discharge≠	72 (75%)	3906 (65%)	27 (87%)	1087 (77%)	45 (69%)	2819 (62%)
To Other Acute Hospital≠	12 (12%)	597 (10%)	2 (6%)	175 (12%)	10 (15%)	422 (9%)
To Rehab Facility≠	7 (7%)	633 (11%)	1 (3%)	69 (5%)	6 (9%)	564 (12%)
To Nursing Home≠	3 (3)	632 (11)*	0 (0)	38 (3)	3 (5)	594 (13)

Table 4.3: MTC triaged older patients (Step 4A) vs TU older patients (Age >55 years)

MTC= Major Trauma Centre, TU= Trauma Unit, GCS= Glasgow Coma Scale, ISS= Injury Severity Score, LOS= Length of stay
* indicates significant difference between MTC and TU ($p<0.05$). Discharge destination and lengths of stay given for survivors only,

Multivariable analysis was performed to determine whether direct MTC admission (i.e. Step 4A/triage-positive patients) was independently associated with on a number of outcomes, namely 30-day mortality, early surgical intervention and length of stay.

Direct MTC admission did not have a significant independent effect on any of the measured outcomes. Increasing age remained a significant independent predictor of increased 30-day mortality (OR 1.09, $p<0.001$) (Table 4.4), reduced likelihood of early surgery (OR 0.97, p<0.001) (Table 4.5) and increased length of stay (β coefficient 0.30, p<0.001) (Table 4.6). Age was specifically a predictor of increased mortality odds in patients aged over 70. The need for ICU admission appeared to be the strongest independent predictor of poorer outcome across the board. Of note it was associated with a 30-fold increase in 30-day mortality in the 56-69 age groups.

Male gender was associated with a reduced likelihood of having an early surgical intervention, specifically in patients aged over 70 (OR 0.45, p<0.01). Despite there being a median GCS of 15 with both MTC and TU patients, lower GCS remained a significant predictor of increased mortality, need for surgery, less favourable discharge destination and longer length of stays which was again more pronounced in the over 70s.

	Age >55		**Age 56-69**		**Age 70+**	
Independent Variables	n=6531		N=1467		N=5064	
	OR (95% CI)	***p value***	**OR (95% CI)**	***p value***	**OR (95% CI)**	***p value***
Admission Age	1.09 (1.07-1.10)	<0.01	0.99 (0.88-1.12)	0.87	1.08 (1.06-1.10)	<0.01
Gender (Male)	1.28 (1.03-1.61)	0.03	0.44 (0.17-1.17)	0.10	1.36 (1.08-1.71)	0.01
Admission GCS	0.73 (0.70-0.77)	<0.01	0.88 (0.77-1.01)	0.07	0.71 (0.66-0.75)	<0.01
ISS	1.05 (1.04-1.07)	<0.01	1.02 (0.96-1.09)	0.58	1.05 (1.04-1.07)	<0.01
ICU admission	4.20 (2.76-6.38)	<0.01	30.21 (10.64-85.79)	<0.01	3.15 (1.94-5.14)	<0.01
Level of Care (MTC)	0.59 (0.23-1.54)	0.28	0.00 (0.00-?)	0.998	0.67 (0.03-1.78)	0.42

Table 4.4: Binary logistic regression analysis of factors associated with 30-day mortality in patients >55yrs

Nagelkerke R-squared: >55= 0.201, 55-69= 0.312, 70+= 0.171 Hosmer-Lemeshow test: >55= 8.91, p=0.35; 55-69= 9.86, p=0.275; 70+= 2.90, p=0.941. Abbreviations= GCS: Glasgow Coma Scale, ISS: Injury Severity Score, ICU: Intensive Care Unit, OR: Odds ratio, CI: Confidence Interval

Independent Variables	Age >55		Age 56-69		Age 70+	
	N=6531		N=1467		N=5064	
	OR (95% CI)	***p* *value***	**OR (95% CI)**	***p value***	**OR (95% CI)**	***p value***
Admission Age	0.97 (0.95-0.98)	<0.01	0.91 (0.84-0.98)	0.01	0.98 (0.96-1.01)	0.22
Gender (Male)	0.65 (0.45-0.93)	0.02	1.07 (0.61-1.86)	0.82	0.45 (0.27-0.75)	<0.01
Admission GCS	1.37 (0.96-1.95)	0.08	2.87 (0.50-16.49)	0.24	1.26 (0.89-1.80)	0.20
ISS	0.97 (0.94-1.00)	0.06	0.94 (0.89-1.00)	0.07	0.98 (0.95-1.02)	0.29
ICU admission	2.30 (1.21-4.37)	0.01	2.40 (0.90-6.38)	0.08	2.40 (1.01-5.66)	0.05
Level of Care (MTC)	0.89 (0.22-3.71)	0.88	0.00 (0.00-?)	1.00	1.84 (0.43-7.80)	0.41

Table 4.5: Binary logistic regression analysis of factors associated with early surgical intervention in patients >55yrs

Nagelkerke R-squared: >55= 0.035, 55-69= 0.055, 70+= 0.025 Hosmer-Lemeshow test: >55=2.405, p=0.966; 55-69= 4.114, p=0.847; 70+=7.141, p=0.522. Abbreviations= GCS: Glasgow Coma Scale, ISS: Injury Severity Score, ICU: Intensive Care Unit, OR: Odds ratio, CI: Confidence Interval

Independent Variables	Age >55		Age 56-69		Age 70+	
	n=5780[a]		n=1365[b]		n=4415[c]	
	β coefficient (95% CI)	***p value***	**β coefficient (95% CI)**	***p value***	**β coefficient (95% CI)**	***p value***
Admission Age	0.30 (0.26-0.34)	<0.01	0.21 (0.03-0.39)	0.02	0.35 (0.27-0.42)	<0.01
Gender (Male)	-0.68 (-1.63-0.27)	0.16	-0.79 (-2.21-0.64)	0.28	-0.62 (-1.79-0.56)	0.30
Admission GCS	-0.89 (-1.38-(-0.40))	<0.01	-0.84 (-1.47-(-0.21))	0.01	-0.92 (-1.57-(-0.28))	0.01
ISS	0.02 (-0.05-0.08)	0.68	-0.05 (-0.17-0.07)	0.42	0.03 (-0.05-0.11)	0.44
ICU admission	10.85 (8.27-13.42)	<0.01	11.53 (8.27-14.79)	<0.01	10.61 (7.18-14.04)	<0.01
Level of Care (MTC)	0.42 (-3.15-3.99)	0.82	-0.68 (-5.43-4.08)	0.78	1.19 (-3.44-5.81)	0.62

Table 4.6: Linear regression analysis of factors associated with length of stay in patients >55yrs

Abbreviations= GCS: Glasgow Coma Scale, ISS: Injury Severity Score, ICU: Intensive Care Unit, OR: Odds ratio, CI: Confidence Interval. Model R^2 values (all ANOVA p-values <0.001)= Age>55: 0.049, Age 55-69: 0.048, Age 70+:0.03

a: regression model excluded 440 dead patients and 311 patients with missing GCS

b: regression model excluded 24 dead patients and 78 patients with missing GCS

c: regression model excluded 416 dead patients and 233 patients with missing GCS

4.4 Discussion

This study examined the relationship between prehospital triage decisions, surgical interventions, and outcomes across a large urban inclusive trauma system. Overall, there was evidence of high rates of over-triage where patients did not obviously require, or benefit from direct bypass to a major trauma centre. This is well illustrated by the fact that 46% of patients survived and were discharged home from MTCs without the need for early surgical intervention or critical care admission. Within the triage tool there were clearly dominant criteria able to select out most patients who would require early surgery or had poor outcomes such as Step 1 and components of Step 2 which identified patients with the highest mortality rates and rates of early intervention. Refining the triage tool to affect these might improve patient experience without affecting outcomes and help to balance both prehospital and in-hospital resource utilisation.

In this study, within the context of the LMTS, a large number of patients triaged directly to an MTC appeared not to require or benefit from this decision given that overall only 23% of patients required an early surgical/radiological intervention. Overall, 534 (46%) of patients survived and were discharged home without the need for early intervention or critical care admission. Early physiological deterioration (Step 1 criteria) was the most important determinant of the requirement for early surgery and of outcomes including mortality, as has been identified in previous studies (17,18). Anatomic criteria (Step 2) were the trigger criteria for nearly half the patients, but in this study only a quarter of Step 2 patients received an early surgical intervention, the majority of which were for extremity orthopedic injuries. Step 2 patients requiring a time-critical intervention are likely to have been concentrated within the penetrating torso trauma group (2C), and overall mortality was very low for Step 2 patients at 2%.

Mechanism of injury alone (Step 3) did identify some patients with serious injury, but no patients died, and only 9% received a surgical intervention within the first 12 hours. Remarkably, this 9% figure is identical to that presented by Lerner et al in their 2-year prospective cohort study of trauma admissions to 3 Level 1 trauma centres (110). Of the 2363 patients triaged using the mechanism step of their triage tool, only 9% were deemed worthy of needing Level 1 trauma care (as determined by non-orthopedic surgery within 24 hours, intensive care unit admission, or in-patient death). Notably in the Lerner study only half of the eligible patients were entered into the study due to lack of 24 hour research staff to conduct the ambulance crew interviews required as part of the prospective study, therefore overnight admissions in particular were missed. This may have biased the results. (i.e. more assaults and falls occurred overnight along with fewer motor vehicle accidents). Injury mechanism may identify high risk patients, however previous studies have repeatedly shown it to be a poor independent predictor of injury severity (111) and need for specialist trauma centre admission (112–114). One exception could be in the triage of elderly patients. A systematic review and meta-analysis by Sammy et al of factors affecting mortality in older patients showed that low level falls were associated with higher mortality than motor vehicle collisions (cumulative odds ratio 2.88, 95% CI 1.26–6.60) (115). This may be a useful consideration given the delayed physiological response to injury such as delayed deterioration of GCS (as discussed in Chapter 3) and blunted cardiovascular responses due to cardiological and neurological co-morbidities or medication use.

Most of the patients in Step 4 were triaged because of their age. Few of these patients received an early surgical or radiological intervention and there were no clear outcome differences between patients aged over 55 year managed at TUs and those age over 55 at MTCs, despite TU patients being older on average, less severely injured and requiring fewer ICU admissions. These findings are in keeping with similar elsewhere. A retrospective cohort study of over 6000 patients aged over 55 by Staudenmeyer et al showed that despite a 33% undertriage ratio, there was no difference in 60-day mortality rates between non-trauma centre and trauma centre patients in both unadjusted and adjusted analysis, however the costs of treating patients at trauma centres were significantly higher (116). In our study, older TU patients were more likely to be discharged to nursing homes, which among other things may reflect the older age of the TU group or perhaps the TU's better access to local community and social care resources. Of note was the wide confidence interval for the odds ratio relating to the impact of ICU admission on 30-day mortality in patients aged 56-69 (30.21 (10.64-85.79). This could reflect the wide variety of co-morbidities and frailty statuses in this late-middle aged group relative to other younger or older age groups, which could be compounded by an admission to ICU. Patients under the age of 55 may expect to have fewer co-morbidities and better health than older patients. However, patients living into their 70s and beyond may have survived or managed chronic health conditions better than their counterparts who die in their 50s and 60s.

Major Trauma Centres are specialist hospitals that concentrate expertise and resources to improve outcomes in patients who have potentially life-threatening or life-changing injuries(29). They must often balance this commitment alongside acting as tertiary units for a wide variety of clinical subspecialties. Most injured patients do not require such specialist resources. These patients require high quality, timely injury care and personal support; yet these elements are not structural and can be delivered by trained and engaged multidisciplinary teams in Trauma Units. By doing so, patients remain closer to home thus improving family contact and streamlining post-discharge community rehabilitation and social care arrangements. Injured patients without critical or complex injuries who do not require specialist care may receive less than optimal care at MTCs due to being repeatedly de-prioritised for more urgent cases. A UK study comparing the effect of MTC designation on the management of elderly patients with neck of femur fractures found a significant increase in delays to theatre (median 6 hour delay post MTC designation) with a consequent increase in post-operative medical complications(18). Non-critically injured patients may also have a more difficult and prolonged discharge process with gaps in post-discharge support due to MTCs not being able to access community services out of their local area. This leads to longer lengths of stay and increased associated costs. Where possible therefore, inclusive trauma systems should ensure that patients who do not require specialist trauma care outside of their local area should be transported to and cared for by their local Trauma Unit.

Based upon the findings of this study, consideration could be given to adjusting the triage tool as follows:

- Removal of all Step 2 criteria except 2C,
- Removal of Step 3 entirely
- Removal of the ʻadvanced ageʼ option from Step 4 (4A)

In this study year, taking into account first triage preference, this could potentially have avoided approximately 600 direct bypasses to major trauma centres. While some of these patients would have subsequently required onward transfer, this is still likely to be over 500 patients each year who could have been managed closer to home with an equal number of ambulance crews who could have stayed within their locality, and approximately 5,000 bed days saved at the Major Trauma Centres.

4.4.1 Limitations and Strengths

This study is limited by its retrospective nature. It was not possible to determine whether the patients directly bypassed to the MTC would have had worse outcomes if they had first been taken to a Trauma Unit. Furthermore, it was only possible to assess a limited number of outcomes. While length of hospital stay and discharge destination are reasonable surrogates for overall care and outcomes, they cannot fully capture complications, functional outcomes or overall patient experience. Hospital length of stay may have been influenced by intended discharge destination (i.e. clinically stable patients awaiting rehabilitation facility placement). Discharge destination was analysed as an outcome and therefore not included as an independent variable in the multivariate analyses, therefore this will not have been adjusted for when looking at length of stay.

The outcomes of triage-negative patients at TUs were not assessed in this study. Therefore no conclusions could be made with regards to the levels of under-triage and the implications this may have for patient outcomes or trauma system overall (i.e. need for secondary transfers).

The limitations of working with TARN data have been described in the previous chapter (Chapter 3.4.1) and include information bias due to clerical errors by non-clinicians recording the data.

The 12 hour cut-off definition for early intervention may have been too broad a time period when considering previous studies that have employed shorter timeframes (typically 2 hours or less) when defining time to emergency laparotomy (117), especially in patients with haemodynamic instability (118,119) and those undergoing interventional radiology procedures (120). However, this is balanced against the fact that MTC admission is not just driven by the need for urgent interventions in shocked patients, but may also be mandated by national guidelines and operational considerations (see Table 5.2).

An element of selection bias may have been introduced by the exclusion of a large number of patients, predominantly those from hospital outside of the Greater London area that nonetheless feed into London MTCs. These patients were unmatchable due to the fact they were conveyed by non-LAS services with no way of us accessing the required prehospital information from these services. This subset of patients (who by definition would have had longer prehospital times) may have presented with different physiology or may have been triaged in a different manner which may have had an impact on the results overall. Thirty percent of the potentially matchable patients could not be matched as ‘strong matches’ were not possible using the deterministic methods detailed earlier (see 4.2.3 Data Linkage). This will have also contributed towards the selection bias. Furthermore, despite precautions being taken, there may have been some cases of matching error owing to the incident-specific nature of the CAD numbering system rather than it being patient-specific, as described earlier in this chapter (4.2.3).

This study was conducted using the deterministic method of data linkage. Deterministic matching or linkage is one of two well-recognised methods for linking identical records between separate databases as was required for this study. A more detailed explanation of the differing linkage methodologies is provided in Chapter 2.3.3. The alternative probabilistic linkage may have provided a quicker and more accurate means of matching records, accounting for the typographical errors inherent in manual entry databases. However, the software required to carry out the process could not be downloaded on to the LAS computers used for this study owing to LAS data protection regulations.

This study was the first collaborative retrospective observational registry study between the Centre For Trauma Sciences (Queen Mary University of London) and the London Ambulance Service. It successfully matched data for the first time between the national TARN database and the London Ambulance Service’s internal patient database, adopting a pragmatic approach to negate the need for patient-identifiable data and to work within the IT and Information Governance policies of the LAS. Areas for potential optimisation of the triage tool were identified.

4.4.2 Generalisability

As with the previous study, the results of this study may be broadly reflective of findings in other similarly sized developed urban trauma systems around the UK. Penetrating torso trauma was identified as a key component of Step 2 and it is worth noting that one of the main differences within the LMTS compared to other trauma systems around the UK, including those encompassing large urban areas is the proportion of penetrating trauma. A 2017 systematic review of penetrating trauma epidemiology in the UK found relative incidences ranged from 0.3% in the Midlands up to 21% in London − the highest in the UK (121). The results of the review may have been skewed by the inclusion of studies that only reviewed major trauma admissions. In our study, there were 181 cases of penetrating injury mechanisms (stabbing or shooting) out of the 1217 matched major trauma patients giving an incidence rate of 14.8% over the 12-month period.

4.5 Conclusion

High-functioning inclusive trauma systems must ensure that patients' needs are matched to hospital resources. The prehospital triage tool is a core function of any trauma system, which sets the destination for most injured patients. Triage tools in many ways set and reflect the philosophy of a system − the choice between a system that is truly inclusive and confident in the capabilities of all trauma receiving hospitals in its constituency, or one that is functionally exclusive and believes good care can only be delivered at the specialist centres. Opportunities to refine the triage tool by placing greater emphasis on physiological derangement as opposed to anatomical injury or mechanistic factors have been identified. This may lead to improved resource use, patient flow and patient experience across this maturing system. Modelling and prospective implementation studies will be required to fully determine the optimal configuration of the triage tool and to provide evidence of improved trauma system efficiency with no significant detriment to patient safety. These refinements are likely to be applicable to many established and future regional trauma systems globally. In the following chapter, changes to the triage tool based on this study's findings were tested in a spreadsheet -based simulation model to test the impact of proposed changes.

Chapter 5: STUDY 3: Modelling Changes to the London Triage Tool

5.1 Introduction

The TuTOR study reported in Chapter 4 made several recommendations for optimising the performance of the LMTS Trauma Triage Tool. Before implementing such changes, it is important to attempt to model their effect across the trauma system on MTC and ambulance workload. Triage tool changes may have significant resource implications for all stakeholders within the system. The development of a computerised simulation model based on the TuTOR data was proposed to test the impact of various individual and combined aspects of the changes on the trauma system.

A system can be defined as a set of interacting components or entities operating together to achieve a common goal (122). Systems can be physical with material components (i.e. factory production line) or abstract with conceptual/non-tangible components (i.e. cultural systems or political strategy). A trauma system, given its physical components of ambulances and hospitals can be considered a physical system. As such, it possible to model how changes may affect its performance. As with many complex real-world systems, full-scale physical modelling can be a logistical impossibility and prohibitively costly both in terms of finances and the diversion of staff away from ongoing health provision. Even scaled-down 'table-top' exercises are limited by the level of complexity achievable with human input. It may be possible to play out specific simple scenarios, but the computational demands of multiple simultaneous scenarios and input changes will quickly overwhelm human physical and mental capability.

Mathematical models serve as a substitute for direct measurement and experimentation in these circumstances. Broadly speaking, mathematical models can be divided into analytical models or simulation models. Analytical modelling allows for the precision modelling of systems that can be summarised in the form of mathematical equations. Examples of this might be found in the world of sales and marketing or in manufacturing industries for monitoring fluxes in stock inventory. Simulation modelling allows for the scaled-down observation of system performance and may be able to at least infer or estimate how real-life systems respond to changes. Simulation is ideal for when a complex system i.e. a regional trauma system, cannot be simply summarised into a mathematical formula.

In 2012 a joint task-force of The International Society for Pharmacoeconomics and Outcomes Research (ISPOR) and The Society for Medical Decision Making (SMDM) published best practice guidelines for the application of mathematical modelling to inform medical decisions and address health-related resource allocation questions (123). A system involving human interaction, the allocation of scarce resource in response to discrete changes and that may also involve geospatial factors is well suited to a simulation model.

A chosen simulation models needs to be reflective of the system being simulated. It is therefore necessary to consider the different types of systems amenable to simulation modelling (124,125):

- Deterministic vs Stochastic- if random behaviour is a significant component of the system, then it is said to be stochastic. Deterministic systems involve no random behaviour with the output almost entirely dependent on the input variables. Randomness may remain a small component of deterministic systems and contribute to the variability of outputs.

- Static vs Dynamic- Static systems do not change significantly with respect to time whereas dynamic systems do.

- Discrete vs Continuous- If the state of a system changes at discrete points (events) then it is said to be discrete, whilst the opposite is true for continuous systems. The labelling of a system (or elements of a system) as discrete or continuous is subjective and may be dependent on the overall objective of the simulation.

To test the impact of discrete triage tool changes on trauma system resource demands (ambulance transfers, hospital and ICU bed days etc) based on the 2016 TuTOR data, we developed a simplified deterministic static simulation model in Microsoft Excel®. Although human decisions are part of a trauma system, the adherence to specific triage criteria removed a large element of randomness and justified its categorisation as a deterministic system.

Where applicable, the remainder of this chapter is set out in line with the international STRESS (Strengthening the Reporting of Empirical Simulation Studies) guidelines (126).

5.2 Objectives

5.2.1 Purpose of model

The overall aim of this study was to use the dataset and recommendations from the TuTOR study to develop a computerised simulation model to examine the potential resource implications of implementing the TuTOR recommendations in the London Trauma System.

5.2.2 Model outputs

A number of outcome measures were recorded from the model output:

Direct MTC admission- new number of patients transported directly to MTC given the removal of a given Step/trigger

- **Primary LAS bypasses avoided**- The number of patients previously transported directly to MTCs, but who no longer met the newly selected triage criteria and were therefore primarily transported to TUs.

Secondary transfers- Patients who no longer met the new triage criteria but who went on to have a critical intervention and therefore justified secondary MTC admission

- **Admissions for non-critical intervention avoided**- The difference between primary LAS bypasses avoided and the number of secondary transfers (the number of patients diverted to TUs and remained there)

- **MTC mortality rate**- 30-day mortality rate amongst patients transported directly to MTCs

- **Transfer mortality rate**- 30-day mortality rate amongst transferred patients

- **TU mortality rate**- 30-day mortality rate amongst patients remaining at TUs

- **Median ISS**- Median injury severity score at MTCs after the new triage criteria had been simulated

- **Percentage ISS>15**- Percentage of ʻmajor traumaʼ patients at MTCs after the new triage criteria had been simulated

- **Direct MTC critical care admissions avoided**- Number of patients diverted to TUs who would have otherwise been admitted to an MTC critical care bed

- **Total MTC critical care admissions avoided**- Number of patients diverted to TUs who would have otherwise been admitted to an MTC critical care bed, factoring in the secondary transfers returning to MTCs for critical interventions.

- **Direct MTC critical care bed days avoided**- Number of saved critical care bed days from the diversion of patients away from MTC to TU. Bed days were calculated as mean critical care length of stay multiplied by the number of patients on critical care.

- **Total MTC critical care bed days avoided**- Number of saved critical care bed days from the diversion of patients away from MTC to TU, factoring in the secondary transfer patients who returned to an MTC for a critical procedure and required critical care admission.

- **Direct MTC hospital bed days avoided**- Number of saved hospital bed days (including critical care stay) from the diversion of patients away from MTCs. Calculated as the mean hospital length of stay multiplied by the number of patients admitted.

- **Total MTC hospital bed days avoided**- Number of saved hospital bed days from the diversion of patients away from MTCs, factoring in patients returning as secondary transfers.

A detailed summary table of how the above outcome measures were calculated in the model is available in Appendix 2.

5.2.3 Experimentation aims

Further to the overall objective stated in 5.2.1 above, specific aims were to assess the impact of triage tool changes on MTC admissions and new secondary transfer burdens on the LAS. This information could influence decision-making by demonstrating the practical and logistical implications of triage tool changes.

5.3 Logic

5.3.1 Base model overview diagram

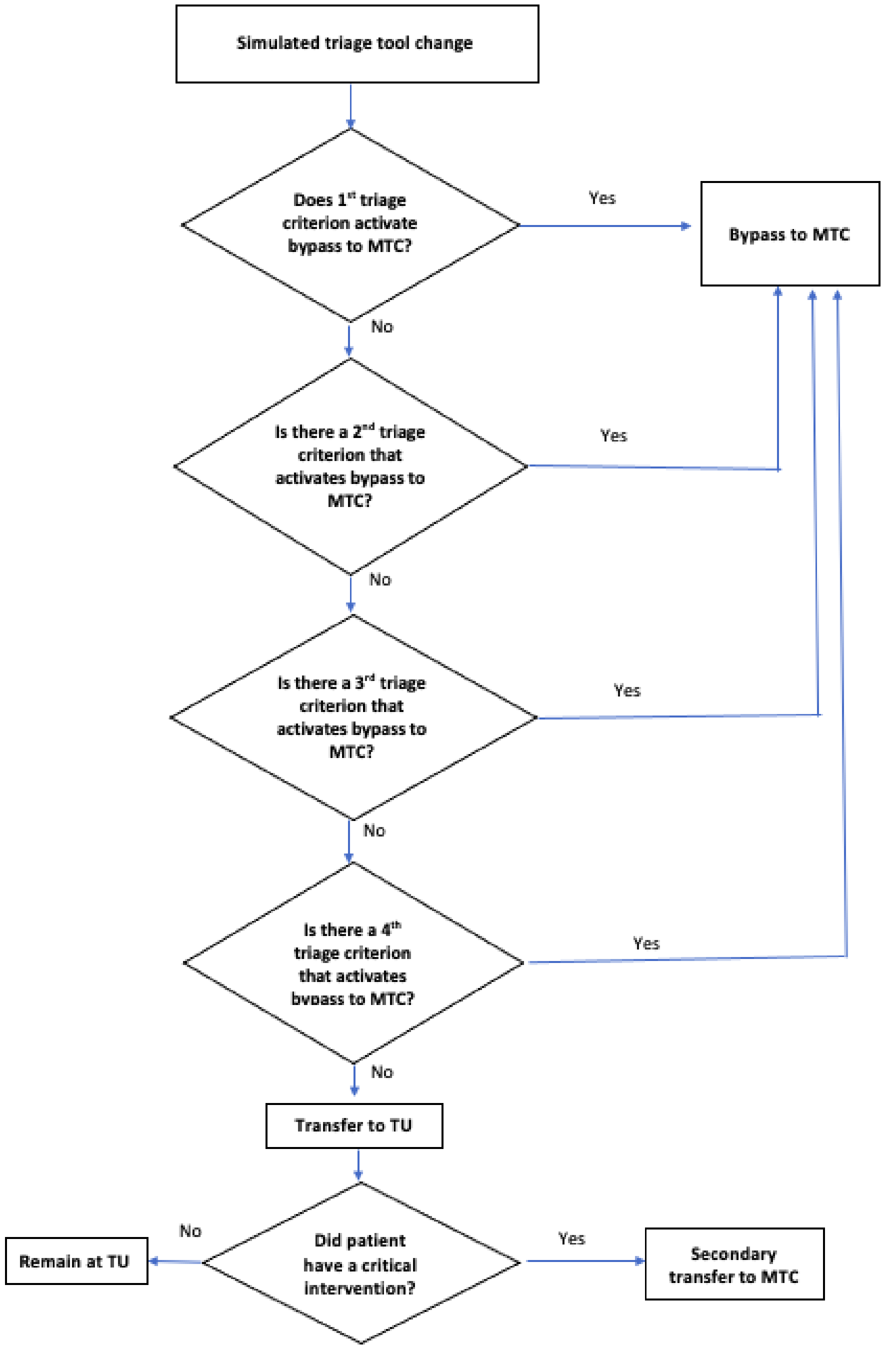


Figure 5.1: Simulation model schematic

5.3.2 Base model logic and algorithms

A simplified deterministic static simulation model was constructed in Microsoft Excel® for Office 365 (version 16) using an output sheet operating as the model front end for the user interface and a back end raw data sheet for informing the model. The back-end data sheet contained rows populated with successfully matched patient records from TuTOR. Relevant data fields listed included:

- Patient age in years
- All possible triage criteria listed in hierarchal columns from 1A to 5
- Step 4A age threshold triggered
- Critical intervention
- Hospital length of stay
- Critical Care length of stay
- Mortality outcome
- Injury Severity Score (ISS)
- ISS >15

The model used macros (coded instructions that allow Excel to run a set of programmed actions) which were coded using Microsoft’s event-driven Visual Basic 6 programming language within the integrated development environment in Excel. Numerical coding was used for calculation of inclusion and exclusion of patients based on triage criteria selection within the user-interface sheet. Model output was instantly updated whenever a discrete change was made within the user interface. The model was also designed to allow for the changing of the step 4A age cut-off. Macros were coded to activate patient records in the background data sheet as and when they met the newly selected age cut-off. Furthermore, it was possible to adjust the simulated patient load through a simple scaling up or scaling down of all cell values. The default patient load was 1157 patients which derived from the original TuTOR cohort of 1217 trauma positive patients admitted January-December 2016, minus 60 excluded patients. These patients were excluded for technical reasons owing to the non-standard hierarchy of triage criteria activated in each case. The model relied on the exact hierarchy of triage criteria listed in the triage tool from 1A to 5 to function and therefore these patients could not be accommodated (Fig 1.4).

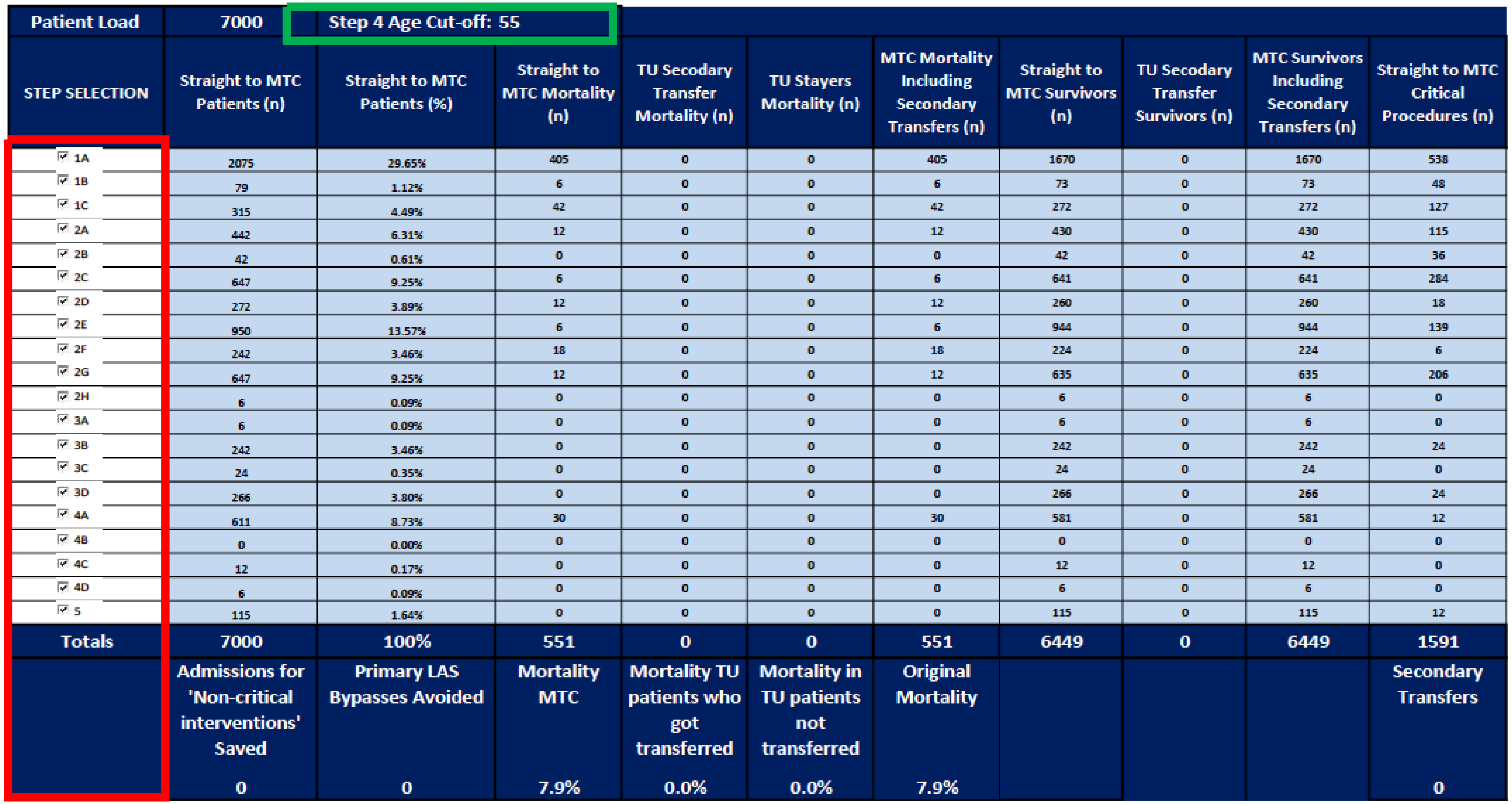
A screenshot of part of the user interface is shown in Fig. 5.2. The first column (highlighted in red) contains the Visual Basic encoded macros that enabled selection and deselection of chosen triage criteria via the checkboxes. The Step 4A age cut-off could be adjusted by entering a value in the green coloured box. The values in the different headed columns adjusted automatically based on the triage criteria selected in the first column.

The background data sheet is shown in Fig. 5.3. Each row of data represents a patient from the TuTOR dataset with their associated triage criteria. The columns to the right highlighted in blue show some of the triage criteria and whether each one was triggered in each patient. Triage criteria were coded with a ‘1’ if triggered and with a ‘5’ if not. For example, the first patient triggered on 1A, 1B, 1C and 2A. Therefore, the columns representing 1A, 1B, 1C and 2A would have contain a ‘1’ whereas all other criteria would be coded ‘5’. Each individual patient could be triaged by up to 4 criteria. For example, a 65-year-old patient who was hypotensive on scene having been stabbed in the chest would trigger 1B, 2A, 2C and 4A (Table 5.1). The hierarchy of the triage tool was such that a Step 1 trigger would always take precedence over any other trigger.

Within the first column of the user interface sheet (red box, Fig. 5.2), each triage criterion was listed in rows and assigned to a cell containing a macro and a COUNTIF function. COUNTIF functions are one of the statistical functions in Excel that allow counting of cells that meet specific criteria. In this case the function linked back to columns in the background data sheet which listed the triage criteria coded ‘1’ or ’5’ (blue box, Fig. 5.2). Selecting or unselecting a triage checkbox in the first column on the user interface would enable switching on and off a chosen triage criterion by switching the ‘1’ to a ‘5’ and vice versa in the respective triage columns on the data sheet. Cells were only counted in the patient total if they were coded ‘1’ and the column to the left (higher up the hierarchy) has been coded ‘5’. This allowed the model to bring into play the 2nd, 3rd and 4th triage criteria as each triage option was switched off by the macros. A logical schematic explaining the model processes is represented in Fig 5.1.

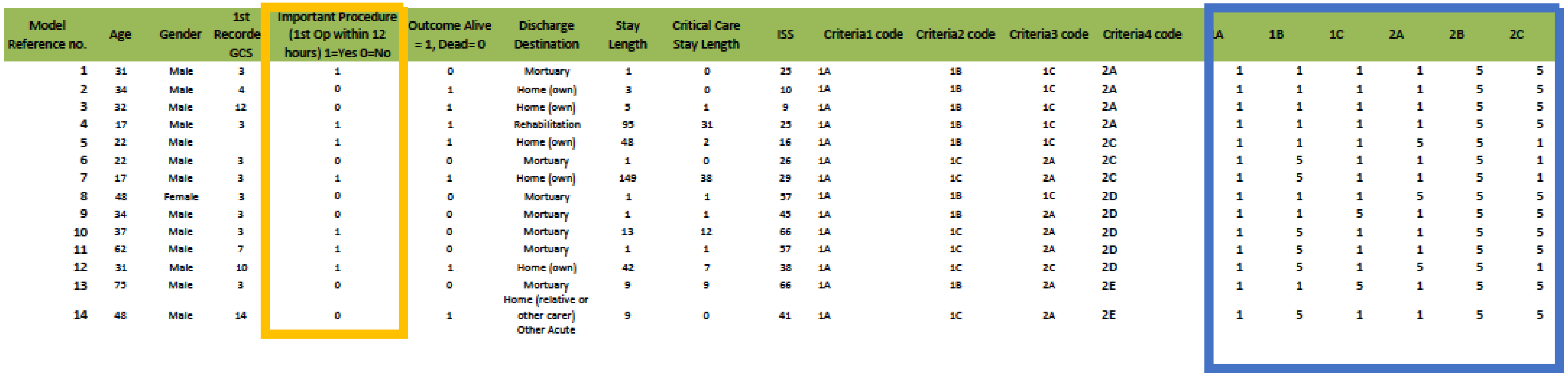
The need for critical surgical intervention (defined as <12 hours from admission) was set as the benchmark for appropriate triage. During any simulated modification of the tool, patients who were subsequently excluded from direct MTC admission because of the triage criteria changes were defined as a secondary transfer if they went on to require a critical intervention (yellow box, Fig 5.3). The difference between the number of direct LAS bypasses to MTC and the number of secondary transfers was used to calculate the total number of MTC admissions saved.

Prior to scaling up patient load, the model was verified by manually cross-checking the redistribution of patients around the system with the removal of different individual and combined triage criteria. This was done to ensure the macros and COUNTIF formula worked as expected. For example by manually filtering the TuTOR patient spreadsheet one could ascertain the expected number of new transfers and TU admissions for any given triage tool alteration based on the 2nd choice of triage criteria used for each patient. The manually calculated results were cross-checked against model output and found to be identical.



Patient Load	7000	Step 4 Age Cut-off: 55								
STEP SELECTION	Straight to MTC Patients (n)	Straight to MTC Patients (%)	Straight to MTC Mortality (n)	TU Secodary Transfer Mortality (n)	TU Stayers Mortality (n)	MTC Mortality Including Secondary Transfers (n)	Straight to MTC Survivors (n)	TU Secodary Transfer Survivors (n)	MTC Survivors Including Secondary Transfers (n)	Straight to MTC Critical Procedures (n)
☑ 1A	2075	29.65%	405	0	0	405	1670	0	1670	538
☑ 1B	79	1.12%	6	0	0	6	73	0	73	48
☑ 1C	315	4.49%	42	0	0	42	272	0	272	127
☑ 2A	442	6.31%	12	0	0	12	430	0	430	115
☑ 2B	42	0.61%	0	0	0	0	42	0	42	36
☑ 2C	647	9.25%	6	0	0	6	641	0	641	284
☑ 2D	272	3.89%	12	0	0	12	260	0	260	18
☑ 2E	950	13.57%	6	0	0	6	944	0	944	139
☑ 2F	242	3.46%	18	0	0	18	224	0	224	6
☑ 2G	647	9.25%	12	0	0	12	635	0	635	206
☑ 2H	6	0.09%	0	0	0	0	6	0	6	0
☑ 3A	6	0.09%	0	0	0	0	6	0	6	0
☑ 3B	242	3.46%	0	0	0	0	242	0	242	24
☑ 3C	24	0.35%	0	0	0	0	24	0	24	0
☑ 3D	266	3.80%	0	0	0	0	266	0	266	24
☑ 4A	611	8.73%	30	0	0	30	581	0	581	12
☑ 4B	0	0.00%	0	0	0	0	0	0	0	0
☑ 4C	12	0.17%	0	0	0	0	12	0	12	0
☑ 4D	6	0.09%	0	0	0	0	6	0	6	0
☑ 5	115	1.64%	0	0	0	0	115	0	115	12
Totals	7000	100%	551	0	0	551	6449	0	6449	1591
	Admissions for 'Non-critical interventions' Saved	Primary LAS Bypasses Avoided	Mortality MTC	Mortality TU patients who got transferred	Mortality in TU patients not transferred	Original Mortality				Secondary Transfers
	0	0	7.9%	0.0%	0.0%	7.9%				0

Figure 5.2: User interface of triage tool model in Excel displaying outcome measures based on triage criteria selection (red) and Step 4A age threshold (green)



Model Reference no.	Age	Gender	1st Recorde GCS	Important Procedure (1st Op within 12 hours) 1=Yes 0=No	Outcome Alive = 1, Dead= 0	Discharge Destination	Stay Length	Critical Care Stay Length	ISS	Criteria1 code	Criteria2 code	Criteria3 code	Criteria4 code	A	1B	1C	2A	2B	2C
1	31	Male	3	1	0	Mortuary	1	0	25	1A	1B	1C	2A	1	1	1	1	5	5
2	34	Male	4	0	1	Home (own)	3	0	10	1A	1B	1C	2A	1	1	1	1	5	5
3	32	Male	12	0	1	Home (own)	5	1	9	1A	1B	1C	2A	1	1	1	1	5	5
4	17	Male	3	1	1	Rehabilitation	95	31	25	1A	1B	1C	2A	1	1	1	1	5	5
5	22	Male		1	1	Home (own)	48	2	16	1A	1B	1C	2C	1	1	1	5	5	1
6	22	Male	3	0	0	Mortuary	1	0	26	1A	1C	2A	2C	1	5	1	1	5	1
7	17	Male	3	1	1	Home (own)	149	38	29	1A	1C	2A	2C	1	5	1	1	5	1
8	48	Female	3	0	0	Mortuary	1	1	57	1A	1B	1C	2D	1	1	1	5	5	5
9	34	Male	3	0	0	Mortuary	1	1	45	1A	1B	2A	2D	1	1	5	1	5	5
10	37	Male	3	1	0	Mortuary	13	12	66	1A	1C	2A	2D	1	5	1	1	5	5
11	62	Male	7	1	0	Mortuary	1	1	57	1A	1C	2A	2D	1	5	1	1	5	5
12	31	Male	10	1	1	Home (own)	42	7	38	1A	1C	2C	2D	1	5	1	5	5	1
13	75	Male	3	0	0	Mortuary	9	9	66	1A	1B	2A	2E	1	1	5	1	5	5
14	48	Male	14	0	1	Home (relative or other carer) Other Acute	9	0	41	1A	1C	2A	2E	1	5	1	1	5	5

Figure 5.3: Background data sheet which provided output data for model based on triage selection (blue) and whether patients had a critical intervention (yellow) thus determining need for secondary transfer to MTC

Step	Triggers	
1 Physiology	• 1A- GCS ≤ 13 • 1B- Systolic pressure <90mmHg • 1C- Respiratory rate <10 or >29	
2 Anatomy	• 2A- Chest injury with altered physiology • 2B- Traumatic amputation • 2C- Penetrating torso trauma • 2D- Suspected open/depressed skull fracture • 2E- Suspected pelvic fracture	• 2F- Spinal trauma with neurological signs • 2G- Open fracture lower limb • 2H- Burns/scalds >30% • 2I- Facial burns • 2J- Circumferential burns
3 Mechanism	• 3A- Traumatic death in same passenger compartment • 3B- Fall >20 feet • 3C- Person trapped under vehicle/large object	• 3D- Bullseye to windscreen
4 Special considerations	• 4A- Age > 55 years • 4B- Pregnant (>20 weeks gestation) • 4C- Anticoagulated patient/bleeding disorder	• 4D- Morbid obesity
5 Crew concern	• 5A- Specific crew concern	

Table 5.1: Triage tool steps and triggers

5.3.3 Simulations

Several different combinations of tool changes were simulated with the model and compared against the baseline data. Across all simulations, the patient load was scaled up to 7000 patients thus representing a typical year's worth of LAS trauma attendance based on 2017-2018 figures (London Ambulance Service, Major Trauma Care Pack Q1 2017/18 Unpublished Internal Report). Simulations performed were as follows:

1. *Non-cumulative removal of individual steps*- In this simulation, triage steps were removed as a whole (i.e. Step 1 removal involved removal of Steps 1A, 1B and 1C). This was performed with each step individually and non-cumulatively.

2. *Non-cumulative removal of individual triggers*- Individual trigger components of each step were removed and replaced in a similar non-cumulative fashion.

3. *Non-cumulative TuTOR changes*- Individual TuTOR changes were made non-cumulatively. A further modification was made to the triage tool which involved removing the steps that weren't associated with any mortality from TuTOR (Steps 3 and 5). The removal of these 'zero mortality' steps was not included in the final TuTOR recommendations as it was recognised that in reality there is always likely be an element of clinical intuition and a need for flexibility (i.e. Step 5- crew concern) which factors into clinical decision-making in some cases.

4. *Changing the Step 4A age cut-off*- In the previous chapter, within the over 55 years patient group, increasing age was shown to be an independent predictor of outcome. Therefore, in addition to outright removal of Step 4A, the simulation model allowed for a more nuanced consideration of the effect of differing age thresholds for triggering direct major trauma centre admission. In this simulation the default Step 4A age cut-off (>55 years) was increased in 5-yearly increments

5. *Full effect of cumulative TuTOR implementation*- The full effect of applying all TuTOR changes in its various forms (see section 5.3.4).

5.3.4 TuTOR variant modelling

Several variants to the TuTOR changes recommended in Chapter 4 were simulated in the modelling. These were based around adjustments to the Step 2 recommendations informed by existing clinical guidelines and further post-hoc changes to Step 4 recommendations based on findings from the model simulations. These variants and the rationale behind them are as follows:

- TuTOR 1- Entirely data-driven changes proposed by TuTOR study:

  -Removal of Step 2 (except 2C)

  -Removal of Step 3

  -Removal of Step 4A

The data-driven Step 2 changes are abbreviated as $\mathbf{2^{DATA}}$

- TuTOR 2- Incorporated clinically-driven Step 2 modifications in addition to other TuTOR changes. These were informed by real-world national clinical guidelines (see Table 5.5.2)

    -Removal of Steps 2A, 2D, 2E only

    -Removal of Step 3

    -Removal of Step 4A

The clinically-driven changes are abbreviated as $\mathbf{2^{CLIN}}$

- TuTOR 3- Incorporates TuTOR 1 but with the Step 4A age threshold raised to >75 rather than complete removal of 4A.

- TuTOR 4- Incorporates TuTOR 2 but with the Step 4A age threshold raised to >75 rather than complete removal of 4A.

Step	**Removed from tool?**	**Rationale**
2A (chest injury)	**Y**	TuTOR results: low association with need for early intervention (14% of Step 2 early interventions, 7% of overall early interventions) and low associated mortality (30-day mortality 3%)
2B (amputation)	N	NICE guidelines recommend that open long bone fractures should be managed at MTCs or specialist orthoplastic centres (NICE guidelines NG37 section 1.1.12) (127)
2C (penetrating torso)	N	TuTOR results: associated with the highest number of early interventions in Step 2 patients (35% of Step 2 early interventions, 18% of overall early interventions)
2D (depressed/open skull fracture)	**Y**	TuTOR results: Low association with need for early neurosurgical intervention (0%) and low associated mortality (<1%). Additionally, neuro-imaging of TU patients can be reviewed remotely by neurosurgeons based at MTCs and appropriate treatment plans instigated
2E (Suspected pelvic fracture)	**Y**	A minority of 2E patients in TuTOR had a confirmed pelvic fracture (Appendix 1). None required pelvic fixation. Haemodynamically stable suspected pelvic fractures unlikely to require direct MTC admission (128).
2F (Spinal injury)	N	NICE guidelines recommend that acute spinal cord injuries should be managed at MTCs (NICE guidelines NG41 section 1.3.2) (129)
2G (open fracture of lower limb)	N	See 2B
2H (Burn/scald >30% BSA)	N	National Network for Burn Care guidance recommends referral to Specialised Burn Services for complex burns* (130)
2I (Facial burns)	N	See 2H
2J (Circumferential burns)	N	See 2H

Table 5.2: Rationale for clinically-guided Step 2 selection (Step 2^{CLIN})

*Includes all burns >3% body surface area in adults (>2% in children), all circumferential burns, full thickness burns and burns to hands/face/perineum/genitalia

The results tables also include the number of patients triaged via each Step or trigger prior to that Step/trigger being removed (*no. patients in group prior to removal*). Due to the hierarchal nature of triage illustrated in Table 5.1, the numbers of patients in each group did not necessarily reflect the number of primary LAS bypasses avoided. For example, a patient triaged via 1A, 2C and 3D will still be taken to an MTC based on 2C even if 1A is removed from the triage tool. Only if all 3 criteria are removed will that patient go to a TU.

5.4 Results

5.4.1 Baseline

A 7000-patient reference load simulation with no tool modifications and therefore no primary bypasses avoided or secondary transfers undertaken gave a baseline MTC mortality of 7.9%. There were a total of 1591 critical procedures, 2311 critical care admissions and 22,010 critical care bed days utilised. Total hospital bed days were calculated to be 132,534. The median ISS of MTC admissions was 15 (IQR 13-18), with 56% of admissions having an ISS greater than 15 (Table 5.3)

5.4.2 Non-cumulative removal of whole steps

The biggest single influence on primary LAS bypass to MTC was Step 2. Removing Step 2 resulted in the avoidance of 2178 direct MTC admissions (primary LAS bypasses avoided), however 29% of these patients went on to require secondary transfer onto an MTC for critical intervention. This left a total of 1537 patients who did not require MTC admission based on the need for critical intervention (Fig. 5.4, Table 5.3).

STEPS REMOVED	**REFERENCE**	**Step 1**	**Step 2**	**Step 3**	**Step 4**	**Step 5**
no. patients in group prior to removal	*n/a*	*2469*	*3248*	*538*	*629*	*115*
Direct MTC admissions	7000	6292	4822	6540	6371	6885
Primary LAS bypasses avoided	n/a	708	2178	460	629	115
Secondary transfers	n/a	194	641	48	12	12
Admissions for 'Non-critical intervention' avoided	n/a	514	1537	411	617	103
MTC mortality	7.9	7.5	11.2	8.4	8.2	8
Transfer mortality	n/a	12.5	0	0	0	0
TU remainer mortality	n/a	10.6	0.8	0	4.9	0
Median MTC ISS (IQR)	15 (13-18)	15 (13-17)	17 (15-19)	15 (13-18)	16(13-19)	16 (13-18)
% ISS> 15 (direct and transfer)	56	56	70	57	57	57
Direct MTC CC admissions avoided	n/a	484	448	61	61	6
Total CC admissions avoided	n/a	309	169	61	61	0
Direct MTC CC bed days saved	n/a	5923	2789	290	230	12
Total CC bed days saved	n/a	3539	1543	290	230	0
Direct MTC hospital bed days saved	n/a	19040	27171	6939	9753	708
Total hospital bed days saved	n/a	12881	16928	5615	9505	623

Table 5.3: Non-cumulative removal of individual steps

CC= critical care

Removal of Steps 3-5 resulted in a smaller number of avoided primary LAS bypasses, with between 2% and 10% of these requiring secondary transfer compared to 27% and 29% for Step 1 or Step 2 removal respectively. Removal of Step 1 resulted in 514 avoided MTC admissions. Despite this figure being far less than the avoided MTC admissions with Step 2 removal, this still translated into the highest number of overall critical care admissions avoided (n=309) and consequently the highest number of critical care bed days saved (3539 bed days). In terms of overall hospital bed days, Step 2 removal resulted in the highest number of saved bed days (16,928 days), with 12,881 bed days saved by removing Step 1.

Figure 5.4: Total number of avoided MTC admissions for non-critical interventions (non-cumulative step removal)

Step 2 removal had the biggest influence on the injury severity of MTC patients with the median ISS increasing from 15 (IQR 13-17) to 17 (IQR 15-19) and the percentage of those with an ISS of >15 increasing from 56% to 70%.

Removing Step 1 did not markedly alter the baseline mortality rate for patients taken directly to MTCs. The mortality rate for patients who would have been secondarily transferred was 13%, whilst 11% of patients remaining at TUs died, both exceeding the MTC mortality rate of 7.5% (Figure 5.5). There were no other deaths observed in the transferred patients when other Steps were removed from the tool, however an increased TU mortality rate was seen with Step 2 (1%) and Step 4 (5%) removal. Removal of Steps 3 and 5 resulted in no increased TU mortality. Increases in TU mortality throughout the simulations was reflective of death being transferred from MTC to TU. It did not represent a death at a TU which would have otherwise survived at an MTC.

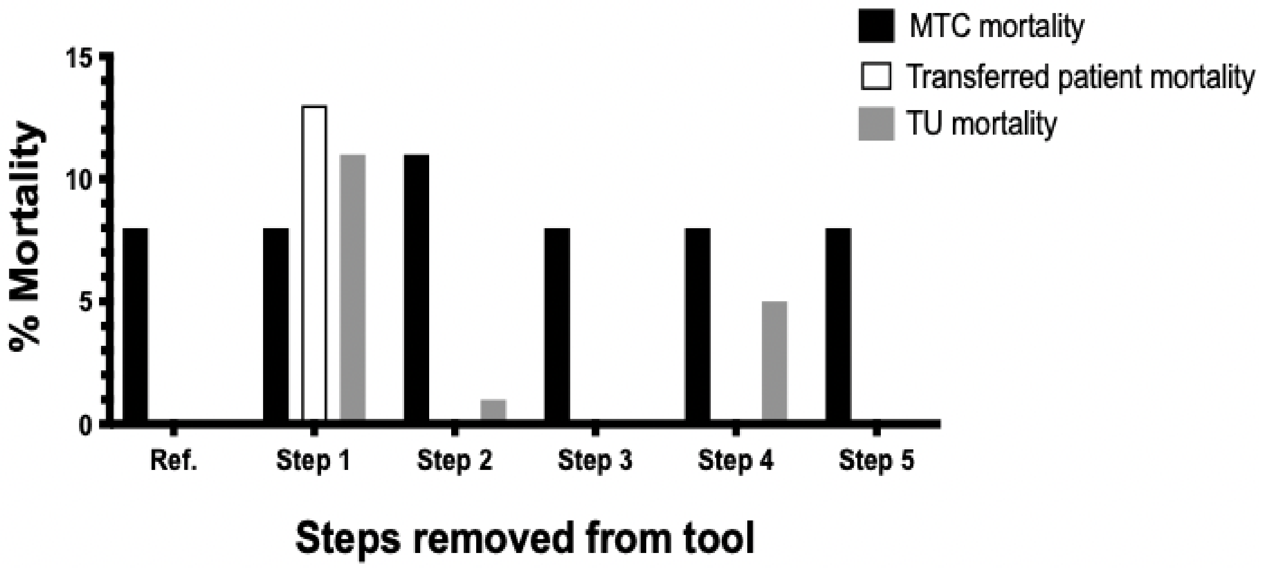


Figure 5.5: Mortality rates for non-cumulative step removal

5.4.3 Non-cumulative removal of individual triggers

Step 4A removal was shown to have the largest individual impact on MTC admission (532 patients) with steps 1A and 2E removal also resulting in a considerable number of reductions (454 and 435 admissions avoided respectively). The need for secondary transfer was most notable with the removal of steps 1A, 2C and 2G. Step 1A removal has the biggest relieving effect on critical care resources with 266 fewer admissions resulting in 2771 critical care bed days saved (Table 5.4).

STEPS REMOVED	**REF**	**1A**	**1B**	**1C**	**2A**	**2B**	**2C**	**2D**	**2E**	**2F**	**2G**	**2H**	**3A**	**3B**	**3C**	**3D**	**4A**	**4B**	**4C**	**4D**	**5**
no. patients in group prior to removal	*n/a*	*2075*	*79*	*315*	*442*	*42*	*647*	*272*	*950*	*242*	*647*	*6*	*6*	*242*	*24*	*266*	*611*	*0*	*12*	*6*	*115*
Direct MTC admissions	7000	6395	6988	6988	6873	6982	6419	6861	6492	6891	6570	6994	6994	6758	6976	6812	6455	7000	6988	6994	6885
Primary LAS bypasses avoided	n/a	605	12	12	127	18	581	139	508	109	430	6	6	242	24	188	545	0	12	6	115
Secondary transfers	n/a	151	12	6	12	18	272	12	73	0	139	0	0	24	0	24	12	0	0	0	12
Admissions for ‘Non-critical intervention’ avoided	n/a	454	0	6	115	0	309	127	435	109	291	6	6	218	24	164	532	0	12	6	103
MTC mortality rate (%)	7.9	7.6	7.9	7.9	8	7.9	8.5	8	8.4	8	8.4	7.9	7.9	8.1	7.9	8.1	8.1	7.9	7.9	7.9	8
Transfer mortality rate (%)	n/a	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TU remainer mortality rate (%)	n/a	9.3	0	0	0	0	2	0	1.4	0	0	0	0	0	0	0	5.7	0	0	0	0
Median MTC ISS	15	15	15	15	15	16	16	15	16	16	16	15	15	16	15	15	15	15	16	15	16
% ISS> 15 (direct and transfer)	56	56	56	56	56	56	60	56	58	56	59	56	56	57	56	57	57	56	56	56	57
Direct MTC CC admissions avoided	n/a	399	12	6	48	12	157	30	79	0	36	0	0	54	0	6	36	0	0	0	6
Total CC admissions avoided	n/a	266	0	0	36	0	36	24	48	0	0	0	0	54	0	6	36	0	0	0	0
Direct MTC CC bed days saved	n/a	4211	296	6	484	18	424	303	1065	0	278	0	0	284	0	6	97	0	0	0	12
Total CC bed days saved	n/a	2771	0	0	194	0	121	224	926	0	0	0	0	284	0	6	97	0	0	0	0
Direct MTC hospital bed days saved	n/a	15289	750	121	1658	914	4919	1458	8222	1234	5560	6	30	4749	472	1688	8204	0	266	42	708
Total hospital bed days saved	n/a	11138	0	12	1016	0	2027	1289	6443	1234	3225	6	30	3914	472	1198	7956	0	266	42	623

Cc= critical care

Table 5.4: Non-cumulative removal of individual triggers

The mortality recorded within the cohort of transferred patients associated with Step 1 removal was specifically related to Step 1A. The removal of this step resulted in a 16% mortality rate among patients requiring secondary transfer. The TU mortality associated with Step 4 removal was specifically shown to be linked to Step 4A which resulted in a 6% TU mortality rate. The small increase in TU mortality associated with Step 2 removal was seen to be specific to 2C and 2E.

5.4.4 Non-cumulative TuTOR changes to tool

The Step 2^{DATA} changes resulted in the largest number of primary LAS bypasses and overall MTC admissions avoided (1434 and 1143 patients respectively) (Figure 5.6). The Step 2^{CLIN} changes resulted in the avoidance of 684 MTC admissions. These changes are reflected in the impact on critical care admissions, critical care bed days and overall hospital bed days (Table 5.5).

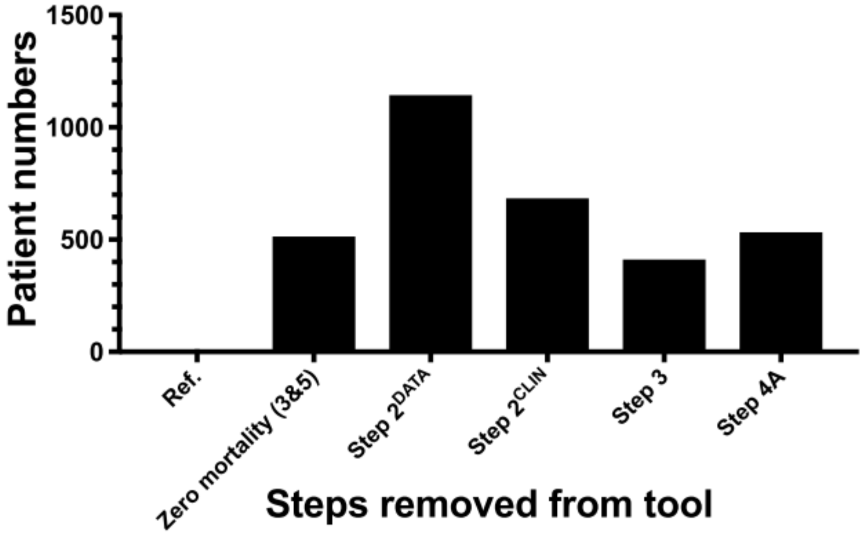


Figure 5.6: Total number of avoided MTC admissions for non-critical interventions (non-cumulative TUTOR changes)

The Step 2^{DATA} modifications resulted in a higher mortality rate at MTCs (up from 8% to 10%) due to the reductions in overall numbers at MTCs. Similarly, removal of Steps 3 and 5, (which accounted for zero mortality) resulted in a relative increase in the MTC mortality rate. This was also noted with the Step 2^{CLIN} modifications (Figure 5.7). Both versions of Step 2 modifications also observed a small increase in the TU mortality rate from 0% to 1%.

STEPS REMOVED	REFERENCE	Zero mortality Steps (3&5)	Step 2^{DATA}	Step 2^{CLIN}	Step 3	Step 4A
Direct MTC admissions	7000	6425	5566	6220	6540	6455
Primary LAS bypasses avoided	n/a	575	1434	780	460	545
Secondary transfers	n/a	61	290	97	48	12
Admissions for 'Non-critical intervention' avoided	n/a	514	1143	684	411	532
MTC mortality rate	7.9	8.6	9.8	8.8	8.4	8.1
Transfer mortality ate	n/a	0	0	0	0	0
TU remainer mortality rate	n/a	0	0.5	0.9	0	5.7
Median MTC ISS (IQR)	15 (13-18)	16 (13-18)	16 (14-18)	15 (13-18)	15 (13-18)	16 (13-18)
% ISS> 15 (direct and transfer)	56	57	62	57	57	57
Direct MTC CC admissions avoided	n/a	67	224	157	61	36
Total CC admissions avoided	n/a	61	115	109	61	36
Direct MTC CC bed days saved	n/a	303	2220	1851	290	97
Total CC bed days saved	n/a	290	1404	1343	290	97
Direct MTC hospital bed days saved	n/a	7647	20812	11386	6939	8204
Total hospital bed days saved	n/a	6238	14067	8797	5615	7956

Table 5.5: Non-cumulative TuTOR changes

The removal of triage steps with no associated mortality (steps 3 and 5) was also modelled. The impact of removing steps 3 and 5 together was marginally greater to that of removing Step 3 alone (in terms of MTC admissions avoided, critical care utilisation and hospital bed days saved) (Table 5.5). TU mortality was highest with Step 4A removal, increasing to almost 6%. Again, this was illustrative of a transfer of mortality from MTC to TU rather than new deaths occurring at TU which would have otherwise survived at MTC.

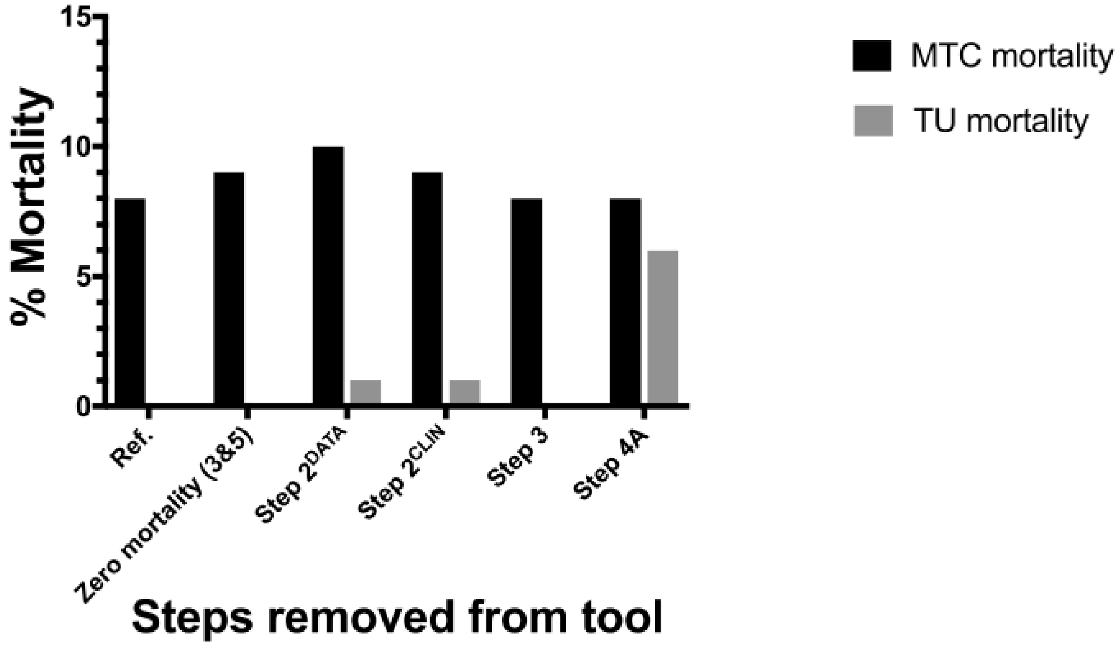


Figure 5.7: Mortality rates for non-cumulative TuTOR changes

5.4.5 Changing the Step 4A age cut-off

Changes to the age cut-off at which Step 4A is triggered (currently >55 years) resulted in a steadily increasing number of avoided MTC admissions, with each age increment up to the maximum effect of removing Step 4A in its entirety (Fig. 5.8). This trend was mirrored in the increased critical care resource savings and overall hospital bed days saved (Table 5.6). The MTC mortality remained at a constant 8% across all age cut-offs. TU mortality began to rise from the >80 years cut-off (2% mortality) up to the 6% mortality seen with complete removal of Step 4A (Figure 5.9). The maintenance of no TU mortality up until >80 years informed the post-hoc creation of the TuTOR 3 and TuTOR 4 variants discussed in the Methods section 5.3.3. The rising TU mortality rate was not reciprocated by a fall in MTC mortality owing to the fact that the overall number of MTC admissions continued to fall in line with the transfer of mortality from MTC to TU.

STEP 4 AGE THRESHOLDS	**REFERENCE (>55 yrs)**	**>60**	**>65**	**>70**	**>75**	**>80**	**>85**	**>90**	**>95**
Direct MTC admissions	7000	6946	6897	6800	6716	6643	6564	6504	6474
Primary LAS bypasses avoided	n/a	54	103	200	284	357	436	496	526
Secondary transfers	n/a	0	0	0	6	12	12	12	12
Admissions for 'Non-critical intervention' avoided	n/a	54	103	200	278	345	424	484	514
MTC mortality rate	7.9	7.9	8	8.1	8.2	8.2	8.3	8.2	8.1
Transfer mortality rate	n/a	0	0	0	0	0	0	0	0
TU remainer mortality rate	n/a	0	0	0	0	1.8	1.4	3.8	4.7
Median MTC ISS (IQR)	15 (13-18)	16 (13-18)	15 (13-18)	15 (13-18)	15 (13-18)	15 (13-18)	15 (14-18)	15 (13-18)	15 (13-18)
% ISS> 15 (direct and transfer)	56	56	56	57	56	56	56	57	57
Direct MTC CC admissions avoided	n/a	6	6	12	18	24	30	36	36
Total CC admissions avoided	n/a	6	6	12	18	24	30	36	36
Direct MTC CC bed days saved	n/a	42	42	48	54	85	91	97	97
Total CC bed days saved	n/a	42	42	48	54	85	91	97	97
Direct MTC hospital bed days saved	n/a	357	871	2154	3424	5131	6534	7623	8101
Total hospital bed days saved	n/a	357	871	2154	3424	5131	6534	7623	8101

Table 5.6: Changing Step 4A age threshold

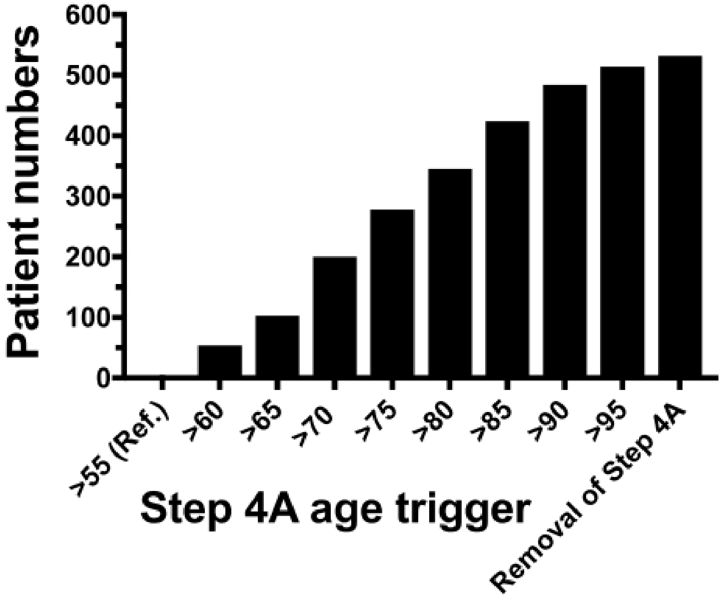


Figure 5.8: Total number of avoided MTC admissions for non-critical interventions (changing Step 4A age threshold)

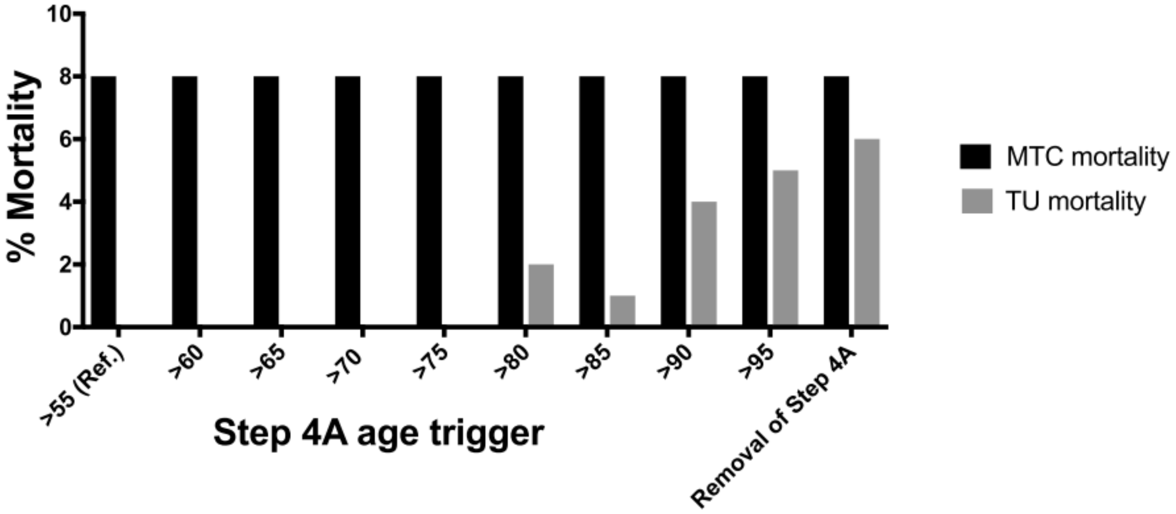


Figure 5.9: Mortality rates for Step 4A age threshold alterations

5.4.6 Full effect of cumulative TuTOR implementation

Within the spectrum of TUTOR changes there was a varying impact on prevented admissions (and subsequent ICU resource utilisation), TU mortality and the secondary transfer burden placed on the ambulance service. Implementation of the most aggressive data-driven version (TUTOR 1) resulted in the highest number of overall MTC admissions avoided (2940 patients). However, this also led to 502 secondary transfers, which was more than any other TUTOR variant (Figure 5.10). The next best alternative in terms of reducing MTC admissions was TuTOR 3 (2481 patients) which involved raising the Step 4A age threshold to >75 (Fig. 5.11, Table 5.7). As expected, the same patterns are reflected in the utilisation of critical care resources (Figs. 5.12, 5.13) and hospital bed days (Figs. 5.14, Table 5.7). There was a greater consolidation of severely injured patients at MTCs with TUTOR 1 with median ISS increasing from 16 to 17 and the percentage of patients with ISS >15 increased from 56% to 73%. TUTOR 1 resulted in the highest transfer of patient morality from MTC to TU (2.5% TU mortality, compared to 0.3% mortality with TUTOR 4).

STEPS REMOVED	REFERENCE	TUTOR 1	TUTOR 2	TUTOR 3	TUTOR 4
Direct MTC admissions	7000	3557	4604	4060	4997
Primary LAS bypasses avoided	n/a	3443	2396	2940	2003
Secondary transfers	n/a	502	200	460	188
Admissions for 'Non-critical intervention' avoided	n/a	2940	2196	2481	1815
MTC mortality rate	7.9	13.4	10.9	13.3	10.9
Transfer mortality	n/a	0	0	0	0
TU remainer mortality	n/a	2.5	2.2	0.5	0.3
Median MTC ISS (IQR)	15 (13-18)	17(13-19)	15 (11-19)	15 (12-16)	15 (9-16)
% ISS> 15 (direct and transfer)	56	73	61	68	60
Direct MTC CC admissions avoided	n/a	484	345	442	321
Total CC admissions avoided	n/a	339	284	309	260
Direct MTC CC bed days saved	n/a	4471	2825	4175	2777
Total CC bed days saved	n/a	3019	2166	2934	2118
Direct MTC hospital bed days saved	n/a	55770	37468	46441	30317
Total hospital bed days saved	n/a	42502	32162	34468	25374

Table 5.7: Cumulative implementation of all TUTOR-recommendations

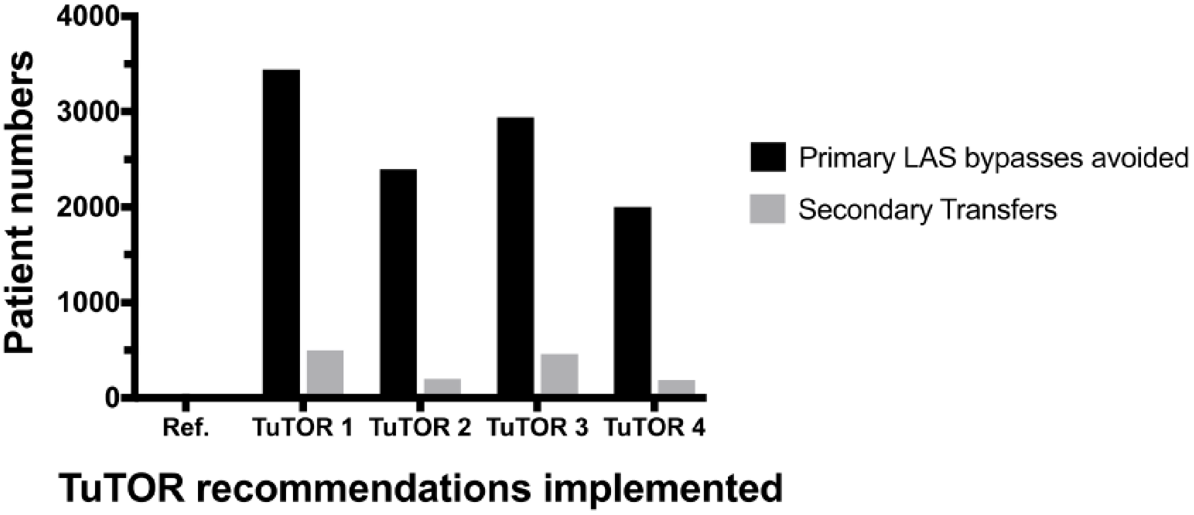


Figure 5.10: LAS bypasses avoided and secondary transfers (full TuTOR implementation)

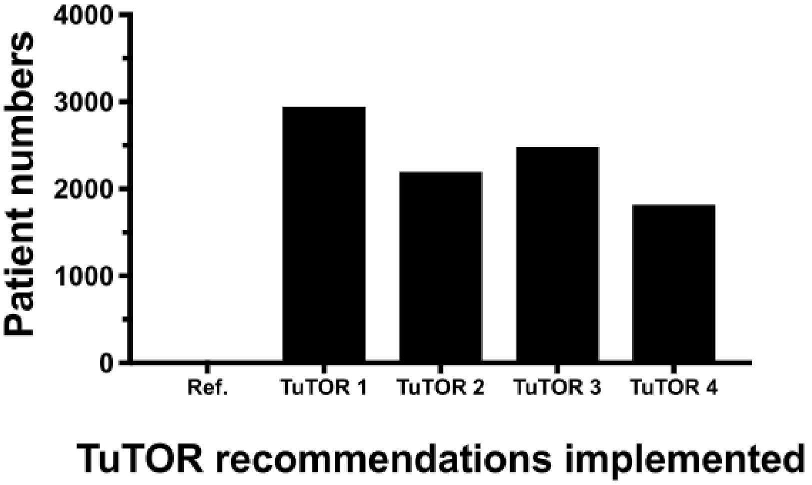


Figure 5.11: Total number of avoided MTC admissions for non-critical interventions (full TuTOR implementation)

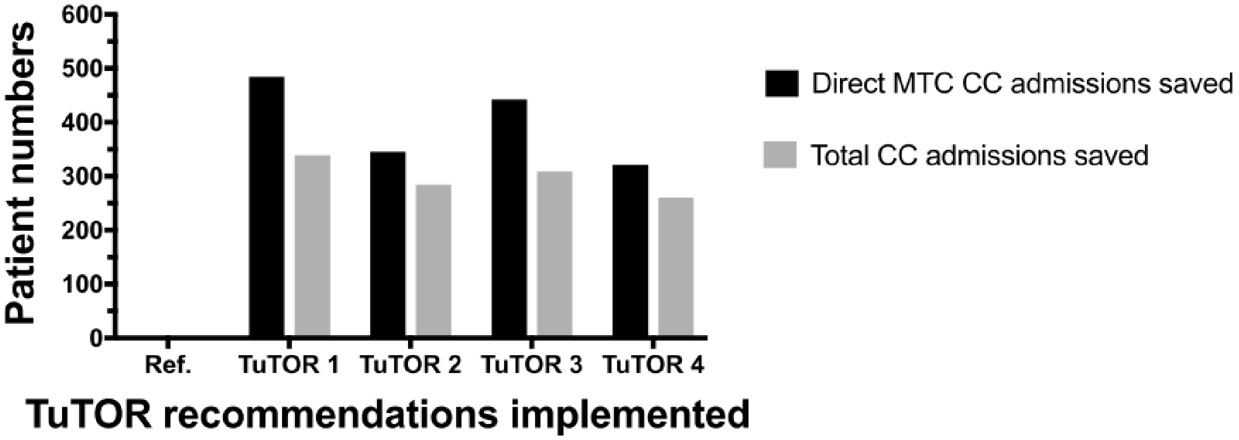


Figure 5.12: Critical Care admissions avoided (full TuTOR implementation)

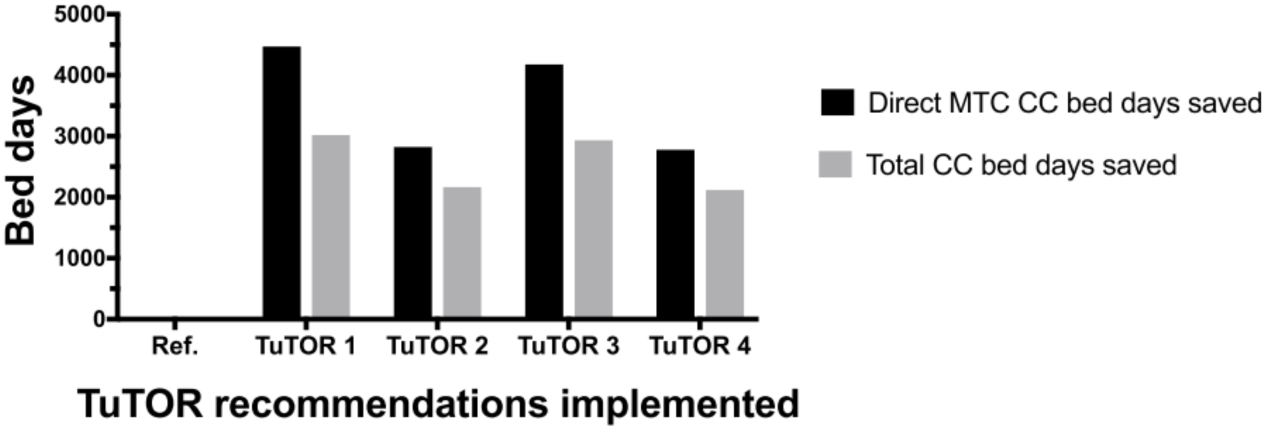


Figure 5.13: Critical Care bed days saved (full TuTOR implementation)

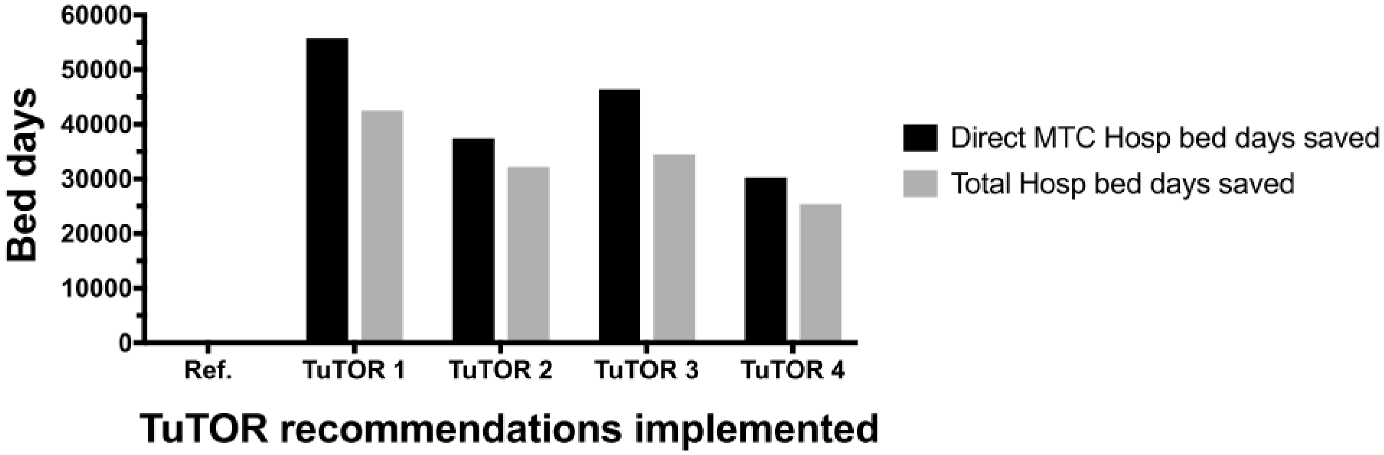


Figure 5.14: Total hospital bed days saved (full TuTOR implementation)

All TuTOR variants increased the relative mortality rate at MTCs as the number of MTC admissions was reduced. TU mortality rates were 2.5%, 2.2% and 0.5% for TuTOR 1,2 and 3 respectively. Following TUTOR 4 implementation the mortality rate of patients remaining at TUs increased minimally to 0.3% (Fig. 5.15).

The simulation model is based upon an original dataset of 1157 patients. Implementing TuTOR 1 on this dataset resulted in 486 patients remaining at TUs. Twelve (2.5%) of those patients died (Appendix 3). Ages ranged from 59 to 97. Five had been triaged primarily on age (4A), three on suspected spinal injury (2F), two on depressed/open skull fracture (2D), one on pelvic fracture (2E) and one on open long bone fracture (2G). Six of the patients had 4A as a secondary triage criterion. Mechanism of injury in 11 of the 12 was a fall, with 8 of these being falls from heights of less than 2m.

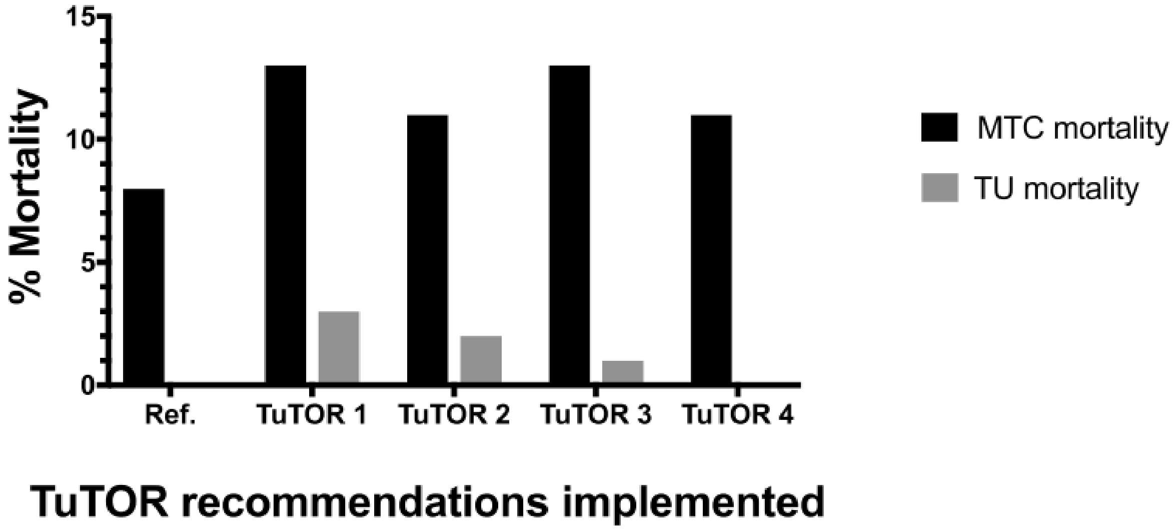


Figure 5.15: Mortality rates for full TuTOR implementation

5.5 Discussion

The primary aim of this study was to examine the effect of triage tool changes on hospital admissions across the London Trauma System. Full implementation of all TUTOR changes achieved a greater reduction in unnecessary MTC admission compared to other non-cumulative implementation of changes to the triage steps. In a typical year with approximately 7000 LAS trauma attendances, the proposed TuTOR changes could prevent up to 2940 unnecessary MTC admissions and save up to 3000 critical care bed days and over 42000 total bed days at MTCs. In our model this led to MTC mortality rates increasing from a baseline of 7.9% in 7000 patients to up to 13.4% with the 4059 MTC patients in the TUTOR-1 variant (total includes direct MTC and transferred patient) owing to a reduction in overall numbers of patients at MTCs. There was also a small increase in the mortality of patients remaining at TUs of up to 2.5%. All new TU mortalities were in patients aged 59-94 with the majority sustaining a major injury burden (ISS>15). Please see Appendix 3 for a further breakdown of this patient population.

There was variation in performance of the different TUTOR options, highlighting the real-world compromises that may need to be considered with regard to reducing primary bypass to MTCs and the consequences this may have on secondary transfer burden and TU mortality. Up to around 500 additional secondary transfers per year can be expected depending on the variant of TUTOR implemented. There may be a need for fairer resource allocation within the trauma system to balance resource savings at MTCs with the increase in ambulance workload.

As previously mentioned, by reducing bypasses to MTCs and keeping more patients at their local hospitals, patients may benefit from being able to receive care in their own community where hospitals may be better set-up to tap into the local services required during and after an inpatient stay. Family and friends within those communities may benefit from easier access to their loved ones in hospital. Elderly patients in particular, with their more complex rehabilitation needs may especially benefit from remaining in their local communities.

There is limited information available on the financial costs of trauma admissions in UK hospitals and how the costs compare between MTCs and TUs. A 2015 analysis of the cost of treating severely bleeding major trauma patients in England and Wales estimated the average initial cost of inpatient care to be £19,770 with approximately two-thirds of the cost attributable to ventilation, ICU and ward stays and 16% attributable to surgery (131). Although the study did not look at specific cost differences between MTC and TU settings it did show in a subgroup analysis of major trauma patients (ISS>15) that their mean total cost of care was over 40% greater than that of less severely injured patients (ISS <15). The article didn’t allude to the cost of MTC level care for patients who weren’t severely bleeding, however it was also noted that costs were higher for elderly patients and those requiring nursing home care. The critical care and total bed day savings predicted by our model with the implementation of TUTOR will likely result in significant financial savings at MTCs.

In our simulation model, increasing the age threshold for 4A activation led to a steady reduction in unnecessary MTC admissions, with TU mortality only rising with an age threshold of over 80 years (Fig. 5.9). Several retrospective studies of trauma mortality have attempted to identify age inflexion points at which mortality increases exponentially. Recently, Fakhry et al performed a trauma registry study of over 250,000 patients and demonstrated statistically significant increases in mortality rate at ages 55, 77 and 82 compared to a reference group aged under 55 years (132). Fatovich et al (133) in a study of 820 trauma patients in Western Australia reported 47 years as the inflexion point for risk of death from “survivable” injuries (ISS 15-24). In a German study of 5400 patients Kuhne et al (134) demonstrated significantly increased mortality in multiply injured patients from age 56, independent of injury severity. A larger US study of over 75000 patients by Caterino et al (135) showed that odds ratios of death increased significantly at the 70–74 year age group, independent of injury severity. Whilst adjusted odds ratios for younger age groups were significantly less than the 70–74 group, there were no significant differences in odds ratios within older groups. This was in contrast to a later study by Curtis et al demonstrating a secondary inflexion point in patients aged over 85 years (136). Our current study further adds weight to the suggestion that raising the age triage threshold captures a higher risk elderly cohort whilst reducing over-triage based on age criteria alone.

A deterministic algorithm model was developed for the purposes of this study which enabled simulation of various modifications to the existing triage tool. There is currently a dearth of medical literature describing the development of similar models for this purpose although there is growing interest around the application of machine learning into developing new, ever-improving triage tools (Chapter 6). Modelling in emergency and trauma care has historically concentrated on optimising emergency department (ED) operational efficiency (137–141) and on simulating resource use and surge capacity during mass casualty incidents (142–146). This commonly takes the form of discrete event simulation (DES) modelling which models the operation of a system as discrete events over time. This technique was used as far back as the late 1980s to model ED nursing shift patterns to improve patient turnaround and reduce queuing time (147). An early example of simulation modelling in trauma triage comes from a study of EMS services in Florida and Georgia, USA in 1993 where a similar DES model was used to simulate changes in Revised Trauma Score (RTS) thresholds, which served as the prehospital triage criteria at that time. Liberalising the RTS cut-off resulted in little effect on the probability of death but led to an increase in helicopter transport and a reduction in ambulance waiting times (148).

In a UK study from 2001 Stevenson et al (149) used an Excel-based simulation model with an add-in Monte Carlo simulation programme to compare triage strategies in traumatic brain injury (TBI) within their neurosurgical regional network and identify those that predicted maximum survivors. Several alternative strategies with the potential to improve survivability were identified as compared to the baseline strategy of taking all patients directly to the nearest hospital.

A number of authors have made attempts to validate their models by comparing the model outputs with real world outcomes (140,141). Altmel et al in their simulation model of emergency surgical bed capacity at an Istanbul teaching hospital compared model output data with data from the actual system. In addition to this they turned to expert opinion by surveying physicians working in the department on the performance of the simulation model during pilot runs(150).

5.5.1 Limitations and Strengths

The current model described in this chapter has several limitations. The model does not test patient safety implications or efficacy as this is only possible following implementation of the changes. The determination of suitability for transfer is entirely dependent upon the patients having had a critical intervention. This may not be a true reflection of transfer appropriateness, furthermore the pre-defined 12-hour cut-off may not reflect the true scope of ‘critical interventions’ which may be delayed beyond 12 hours for a number of complicated logistical or case-specific reasons. However, this was the most pragmatic definition given the limitations of the TARN registry data utilised for the study.

The model was not externally validated due to lack of access to additional datasets with linked triage decision and patient outcome fields, thus comparison with real world systems was not feasible. An alternative validation method may have been expert intuition, however, the challenge of identifying an unbiased trauma system expert from within or outside the London network to assess model functionality was deemed impractical. The deterministic nature of the model meant that randomness and uncertainty could not be adequately accounted for.

This model was developed from a single year’s worth of MTC admissions within the London Major Trauma System and therefore it’s generalisability to other UK or international trauma systems may be limited. Future iterations of the model will ideally be built from a larger and more diversified data set, although database linkage in these circumstances would most likely require dedicated software to facilitate a probabilistic linkage approach. Local data protection rules prevented the installation of such software on the LAS computers used to conduct the TuTOR study that provided the data for this model (Chapter 4).

Despite being unable to provide a full cost-utility analysis owing to the lack of MT and TU specific health cost data, this current model has the advantage of providing data pertinent to health economic considerations such as ‘bed days saved’ as well as clinically relevant data such as mortality. Few models to date have looked at the specific issue of trauma triage outside of mass casualty settings, rather many have been developed to streamline patient flow in emergency departments and provide data for staff planning. The model had added utility for ambulance services by quantifying primary bypass and secondary transfer numbers thus giving an indication of changes to ambulance workload.

This current model was developed using data from triage positive patients. Therefore any predictions made regarding changes in workload across the system do not factor in the population of triage negative patients who are admitted to an MTC because that happens to be their local hospital. In other words, MTCs also function as TUs for their local population. Since the model was developed, unpublished internal data from the LMTS shows that in 2018 there were 5829 MTC admissions of which 520 (9%) were triage negative. The following year saw 6121 MTC admissions of which 636 (10%) were triage negative. These consistent figures suggest that our model still accounts for the vast majority (approximately 90%) of admissions across the LMTS.

5.6 Conclusion

In conclusion this study has demonstrated the use of a deterministic algorithm-based model for simulating potential changes to an existing prehospital triage tool and the implications of these changes on patient outcomes, MTC resource utilisation and prehospital service burden.

In our study, full implementation of all TUTOR changes achieved a greater reduction in unnecessary MTC admission compared to other non-cumulative implementation of changes to the triage steps, with a small increase in TU mortality in patients who had died at MTCs without undergoing a critical intervention.

Simulation models rarely capture the full breadth of human and organisational responses to new guidance and its implementation, therefore future work should aim to evaluate the real-life impact of triage tool changes with further prospective studies to further refine the model.

Chapter 6: Conclusions

6.1 Summary of findings

6.1.1 Chapter 3: Triage in Traumatic Brain Injury

A retrospective study of over 6000 isolated moderate and severe TBI patients comparing outcomes between conservatively managed TU and MTC patients and separately outcomes in patients who required neurosurgery having been directly admitted to an MTC versus those secondarily transferred from TUs.

Patients requiring secondary transfer for neurospecialist care did not experience worse outcomes than those admitted directly to an MTC. On the contrary, elderly patients admitted directly to MTCs for neurospecialist care had an increased risk of mortality within 30 days compared to the transferred patients. Few differences were seen between conservatively managed patient groups in differing levels of care. Our study suggests that within this isolated TBI population it may be safe and beneficial from a system-level perspective to manage greater numbers of patients at Trauma Units provided robust transfer protocols are in place.

6.1.2 Chapter 4: TuTOR study

A retrospective registry study of 1170 patients matched between the prehospital trauma database of the London Ambulance Service and the TARN trauma registry comparing prehospital triage decisions with patient outcomes and need for MTC admission. Identified opportunities for reducing the level of overtriage by removing most anatomical triage criteria and all mechanism and age-related triage criteria from the existing London triage tool.

6.1.3 Chapter 5: Modelling Changes to the London Triage Tool

Developed an Excel-based computer simulation model to test how changes to the London Triage Tool might impact on patient flow across the London Trauma System, in particular the numbers of MTC admissions that might be avoided and how this will impact on secondary transfer requirements and resource utilisation.

Based on a typical year of 7000 LAS trauma attendances, the proposed TuTOR changes could prevent up to 2940 unnecessary MTC admissions and save up to 3000 critical care bed days and over 42000 total bed days at MTCs. This would be accompanied by a 3-5% relative increase in MTC mortality owing to a reduction in overall numbers of patients at MTCs. There would be a small increase in the mortality of patients remaining at TUs of up to 2.5%.

6.2 General discussion

Multiple prior studies and how these tie in with this current body of work have been discussed in the relevant chapters. The overriding message of this thesis is that a greater number of physiologically normal trauma patients may benefit from admission at their local TU rather than direct transport (bypass) to a regional MTC, without any significant detriment to their outcomes. Current levels of overtriage place a strain on health resources, potentially reducing the quality of care offered to all patients at MTCs. Furthermore, patients are needlessly taken to tertiary centres which may be outside of their local community, disrupting social support networks and complicating discharge planning and rehabilitation placements. Whilst adopting a more specific triage policy may shorten hospital journey times for some ambulance crews there will inevitably be a small increase in secondary transfers requirements for the group of patients who are initially under-triaged. Any increase in workload should ideally be matched with an increase in financial and human resources to the affected ambulance services. The same may apply to TUs which will experience an increase in trauma attendances to the emergency department and subsequent admissions. Health planners at regional and government levels will need to find a way to channel the cost savings at MTCs from reduced admissions towards the parts of the trauma system being placed under greater strain.

Patient safety is paramount, therefore any increase in TU mortality stemming from implementation of TuTOR requires further examination. More work is needed to identify which groups of patients will have poor outcomes as a result of TU admission despite not having any initial physiological derangement that would have prompted primary admission to an MTC. Work will also be needed to improve the identification of deteriorating patients at TUs and expedite transfer to MTCs. Examining the TU mortality from TuTOR (Appendix 3) it appears that the patient group most likely have the worst outcome from TU admission were elderly patients injured in falls, particularly low energy falls from standing height. This finding is in keeping with previous studies which have shown an increased need for MTC admission in elderly patients with certain mechanisms (115). A retrospective review of trauma patients aged 70 and above showed a survival benefit of MTC-equivalent care was only evident in patients aged over 77 with significant mechanisms (151). There may therefore be an argument to maintain the injury mechanism step for a select group of elderly patients.

In Chapter 3 it was suggested that greater multidisciplinary care involving early geriatrician input could help reduce mortality among elderly TBI patients triaged directly to MTCs for neurosurgery. Equally there should be a push for greater geriatrician involvement in the care of elderly trauma patients at TUs. Based on demographic trends, TUs are likely to experience increased numbers of elderly trauma admissions irrespective of any proposed changes to the triage tool(85). It's likely that co-morbidities and frailty had a role to play, although this data was not recorded in the TARN data used for my studies. Irrespective of comorbidities, age is an independent risk factor in trauma mortality (115).

6.3 Strengths and limitations of the research

This research was a comprehensive evaluation of a maturing urban inclusive trauma system. It's findings have been taken on board by senior decision makers within NHS England and NHS Improvement and it has helped to shape trauma triage practises during the COVID pandemic and going forward. It has demonstrated the utility of simulation modelling and formed some of the first collaborative work undertaken between the London Ambulance Service and academic departments embedded within the London Trauma System. It is the first time efforts have been made to scientifically link prehospital triage decisions with in-patient events and longer term outcomes. It is hoped that lessons learned from the London experience will be shared with colleagues around the UK and beyond, much in the same way that lessons learned from the setup of the UK's first trauma system in London helped to shape trauma system implementation around the country.

Limitations of the individual studies comprising this thesis are detailed within the relevant chapters. Some limitations related to the chosen outcome measures used throughout this research are also addressed in Chapter 2.

The use of 30-day mortality featured prominently as an outcome measure throughout this research, but this clearly has limitations as a gold-standard outcome measure. Survival of an injury does not necessarily equate to return to normal function or return to work, which may have profound effects on a patient's quality of life as well as the lives of their dependents and loved ones. Advances in life-sustaining therapies also mean that many deaths may occur beyond the 30-day mark, often following brainstem death and prolonged and sensitive interactions with families and on occasions their legal representatives about withdrawal of care. Patient deconditioning and frailty will also inevitably contribute to late deaths, especially in relation to the elderly trauma population. A retrospective cohort study of over 432,000 US veterans with mean age 61 (SD=12.9) categorised patients into frailty groups as per the Risk Analysis Index. It found that the frailest group of patients undergoing moderate stress procedures (i.e. laparoscopic cholecystectomy, laparoscopic colectomy and major lower limb amputation) had respective 30, 90 and 180-day mortality rates of 19%, 34% and 43%. This compared with 0.3%, 0.6% and 1% respectively for the least frail group of patients undergoing the same type of procedures (152). As well as demonstrating the importance of looking beyond 30-day mortality it also gives further credence to the use of frailty scores as a better predictor of patient outcomes than age alone. Therefore a greater effort needs to go into collecting better quality frailty data at MTCs and TUs to feed into TARN.

There was little access to long-term outcome data, namely Glasgow Outcome Scores. This research used TARN data collected during the 3-year period 1st January 2014 to 31st December 2016. During this period thirty-day mortality data only applied to patients who died as inpatients. Patients who were discharged and died outside hospital within the 30-day post admission period were potentially excluded from the data. Whilst their deaths may not have been related to their original injury, they remain a group of mortalities that would be of interest to researchers.

Overall, it is worth reiterating that the primary source of data for this work was retrospective data from the TARN registry. Data is manually entered into the registry by non-clinical administrative staff with resultant inaccuracies in certain aspects of clinical information, for example the mistaking of terms 'thoracotomy' and 'thoracostomy'. Upon receipt of a set off data, time had to be dedicated to cleaning, arranging, and filtering the data to facilitate data analysis. Despite this, elements of missing data and information bias will inevitably persist. Recognised methods for dealing with missing data such as multiple imputation were not considered due to the relatively low amount of missing data from the variables of interest. In Study 1 the missing GCS and discharge data accounted for 4% and 1% of the total study population respectively. For Study 2 these respective figures fall to 0.6% and 0.3%. Missing GCS data accounted for 5% of the 6340 elderly TU patients used to examine the age-dependent triage step in Study 2.

As new methods of clinical assessment and decision-making aids come into use, trauma registries such as the TARN registry may frequently find themselves out of step with the data capture requirements of a continually evolving trauma management field. In recent years growing numbers of institutions have incorporated viscoelastic haemostatic assays such as thromboelastography (TEG) and rotational thromboelastometry (ROTEM) into their major haemorrhage protocols (153). By bringing in new innovations from the academic laboratories into the resuscitation bays for routine use by clinicians, entirely new categories of data which may be of future research and clinical use are generated.

Statistical analysis relied upon multivariable regression analysis in the form of binary logistic regression and linear regression. Measures of model goodness of fit were described in Chapter 2 (2.4 - Statistical Methods) and measurement outputs were detailed beneath the relevant results tables. Nagelkerke R-squared values did not exceed 0.5 in any of the binary logistic models presented, suggesting not all variability in the dependent variables were accounted for by the independent variables. R-squared values for linear regression did not exceed 0.24. Nonetheless, Hosmer-Lemeshow p-values were all non-significant indicating that all the binary logistic regression models presented in this body of work do have predictive value. Ultimately prospective studies and randomised trials incorporating triage tool changes are the only way to provide truly robust statistical evidence of impacts on patient outcomes.

6.4 Generalisability

This research utilised TARN data collected from TUs and MTCs in the London Major Trauma System and was centred around optimising the London triage tool. There are important differences that set the London Trauma System apart from other UK systems. It is a densely populated region with a large number of district general hospitals and large teaching hospitals in relative close proximity to each other. Ambulance response times to the scene of high-category incidents and hospital journey times whether by road or air are relatively short. Large hospitals within London that are not Major Trauma Centres but nonetheless operate as tertiary referral centres and national centres of excellence for other non-trauma related conditions may still be able utilise their enhanced resources, expertise and care processes to assist in their roles as Trauma Units compared to other smaller Trauma units around the country (i.e. easy availability and rapid reporting of cross-sectional imaging 24 hours a day, interventional radiology capabilities, well-staffed physiotherapy and occupational therapy departments, large critical care units and multiple on-site surgical specialities). Furthermore the pattern of trauma seen in London is unique to the UK in terms of the high proportion of penetrating trauma. In 2017 Bew et al published a systematic review on the epidemiology of penetrating injuries in the UK (121). They found the penetrating injury rate in London to be 21% compared to the next highest UK region of Scotland (8.7%). The rest of the UK saw penetrating injury incidences of around 7%. This coupled with the knowledge that penetrating trauma is predominantly a disease of younger men, and that age is a known independent predictor of trauma survival highlights some of the factors that need to be considered when extrapolating London-based trauma studies to the rest of the UK.

However, we still believe the results of this research can be applied to other urban trauma systems around the UK. London was the first part of the UK to implement an organised trauma system, effectively acting as a UK pilot study for the effectiveness of trauma systems and therefore making it an ideal setting in which to trial changes to the triage tools that have been used since the systems became operational. Changes and recommendations from London-based research can be modified as per the regional requirements of other systems around the country.

6.5 Future work

On a global scale there remains much fundamental work to be done. A review of worldwide trauma systems found that the majority of mid-low income countries lack any organised system of trauma care despite accounting for 90% of all lethal traumatic injuries (154)

For systems that are already in place, machine-learning algorithms and elements of artificial intelligence are increasingly being incorporated into modern trauma triage. In 2011 a team of computer scientists from the Tennessee Technological University published their work comparing the existing ACS triage tool with 3 alternative machine learning algorithms. They used 3 years of data from the North Carolina Trauma Registry and looked at several outcome measures to determine MTC suitability, namely death in ED, ED disposition to theatre, ICU admission and ISS>15. ROC curve analysis showed that while none of the machine learning algorithms outperformed the ACS tool, they didn’t demonstrate inferiority (155). Furthermore, and perhaps most crucially they demonstrated the ability to learn in real -time from incorrect triage decisions. An inherent flaw in the current triage paradigm is that decisions are static and do not incorporate a systematic feedback system enabling triage rules to evolve based on previous wrong decisions. This is the strength of machine-learning. A further observation from the study was that whilst machine-learning triage algorithms would continue to improve, they will be hampered by the quality and types of data collected by trauma registries, given that registries tend to be designed for accreditation and performance improvement rather than decision supports. There is a need for data that more accurately mirrors information used by clinicians.

Technology may also have a role to play through the integration of real-time clinical data collected via smart watches and other internet-connected wearable devices. In 2018 a Korean team led by Kim et al successfully produced a data-driven artificial intelligence model for prehospital triage which incorporated vital signs from wearable device(156). Developed for the automatic triage of mass casualties in the absence of medical personnel it used vital signs and a consciousness index to feed into a machine-learning classification model of predicted survival. The consciousness index was a modified GCS score using verbal and motor responses detectable by the wearable device. At some point in the not-too-distant future, ambulance crews may well be able to tap into real-time patient data and accurately determine the need for MTC-level care. A Dutch trial is currently underway to assess the use of a machine-learning prediction model for trauma triage for possible incorporation into a smartphone application by emergency medical staff (157,158).

6.6 Closing remarks

For any changes in triage practice to be successful there needs to be buy-in from the TUs expected to shoulder an increased burden of trauma admissions. Many TUs may have limited institutional experience of dealing with patients with anything more than minor injuries. Despite this, TUs may find themselves having to manage major trauma patients as part of major incident and mass casualty contingency plans. An inclusive system can support TUs with MTC-led teaching and simulation-based training programs, more collaboration between hospitals, and joint clinical governance and quality improvement programs (32,159,160). MTC consultants and clinical managers could potentially have regular TU secondments built into their work plans and equally TU staff may benefit from secondments at MTCs within their network. Human interaction and the building of collegial working relationships and mutual understanding of shared challenges is an important part of the success of any system or large organisation; perhaps more so than written protocols, algorithms or clinical policies. In a system where there is confidence in the clinical capabilities of TUs and the organisational aspects for arranging timely onward transfer and reception, higher degrees of what would previously have been seen as under-triage could potentially be tolerated.

6.7 Emergency implementation of new triage tool (COVID-19 pandemic)

The COVID-19 pandemic placed unprecedented demands on all aspects of the NHS. As part of the London Trauma Steering Group's plan for maintaining major trauma capacity during the pandemic, special authorisation was given to fast-track the enactment of changes to the London triage tool based on our modelling data. The implemented triage tool was a modified version of the TuTOR recommendations (Appendix 5) incorporating some of the clinical considerations detailed in the TUTOR-variant modelling section of this thesis (5.3.3, Table 5.2). In March 2020 a letter was sent out by the Clinical Director of the London Major Trauma System to all stakeholders detailing the changes (Appendix 4) along with the supporting modelling data (Appendix 6).

The new tool remains in operation to date with no significant concerns reported from TUs or the London Ambulance Service. A formal audit of the performance of the new triage tool is shortly to commence.

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Appendix

Appendix 1: Step 2E (suspected pelvic fracture) patients from TuTOR study

- 157 patients triaged as 2E- 29% of all Step 2 triages
    - 67 (43%) confirmed pelvic fractures (+/- femoral/acetabulum)
    - 44 (28%) femoral shaft/NOFs (no pelvis fracture)
    - 4 (3%) acetabulum fractures only
    - 42 (27%) non pelvis/femur/acetabulum

Appendix 2: Model outcome measures

GLOSSARY OF TERMS IN MODEL OUTPUT SPREADSHEET		
Column name	**Explanation**	**How the formula works**
Straight to MTC (n)	No. of patients going straight to MTC in each step	Uses formula in the adjacent Step Selection column which has the macro button. Uses COUNTIF formula which only counts patient if the preceding columns are coded as not active thus accounting for structural hierarchy of the triage tool. Then multiplies this no. by the scaling factor which adjusts for different patient loads (as the model is trained on a specific dataset therefore numbers need to be scaled up/down accordingly)
Straight to MTC (%)	Percentage of total patients per step	The output from the COUNTIF formula divided by total patient load
Straight to MTC mortality (n)	Mortality per triage step	SUM(COUNTIF…) formula that totals the no. of dead patients in the coded mortality column only if that patient is active (as per the COUNTIF formula above). Then multiplies this no. by the scaling factor.
TU Secondary Transfer Mortality (n)	In the context of the chosen Step Selection these are the dead patients who no longer triggered automatic MTC admission but went on to have a critical procedure and therefore would have required secondary transfer	SUM(COUNTIF…) formula that identifies the patients who would no longer trigger any activation if the selected step were removed and within them totals the no. of dead people who had a critical intervention. Multiplied by scaling factor.
MTC mortality including Secondary Transfers (n)	Total mortality of the patients taken direct to MTC and the TU secondary transfer (Straight to MTC mortality + TU Secondary Transfer Mortality)	SUM of the two columns
Straight to MTC survivors (n)	Survivors per triage step	SUM(COUNTIF…) formula that totals the no. of surviving patients in the coded mortality column only if that patient is active (as per the COUNTIF formula above). Then multiplies this no. by the scaling factor which adjusts for different patient loads (as the model is trained on a specific dataset therefore numbers need to be scaled up/down accordingly)
TU Secondary Transfer survivors (n)	In the context of the chosen Step Selection these are the surviving patients who no longer triggered automatic MTC admission but went on to have a critical procedure and therefore would have required secondary transfer	SUM(COUNTIF…) formula that identifies the patients who would no longer trigger any activation if the selected step were removed and within them totals the no. of surviving people who had a critical intervention. Multiplied by scaling factor.
		SUM of the two columns

MTC survivors including Secondary Transfers (n)	Total survivors taken direct to MTC and the TU secondary transfer (Straight to MTC survivors + TU Secondary Transfer survivors)	
Straight to MTC critical procedures (n)	Total no. of critical procedures among the triaged MTC patients	SUM(COUNTIF…) totalling the activated critical procedures column. Multiplied by scaling factor.
TU Critical Procedures (Secondary Transfers) (n)	In the context of the chosen Step Selection these are the patients who no longer triggered automatic MTC admission but went on to have a critical procedure and therefore would have required secondary transfer. Should equate to the sum of TU Secondary Transfer mortality and TU Secondary Transfer survivors	Same SUM(COUNTIF) as the other secondary transfer columns without involving the mortality status column.
Total Critical Procedures	Total procedures for MTC and transferred patients	Sum of the relevant columns
Straight to MTC CC Admission	Direct MTC admissions who went to Critical Care (CC)	SUM(COUNTIF…) totalling the activated patients who had CC stay greater than zero days. Multiplied by scaling factor.
TU Secondary Transfers requiring CC Admission	CC admission for those who would have not gone direct to MTC but went on to have critical procedure and therefore would have required secondary transfer	SUM(COUNTIF…) formula that identifies the patients who would no longer trigger any activation if the selected step were removed and within them totals the no. of patients with CCLOS >0 days. Multiplied by scaling factor.
MTC Admission including Secondary Transfers	Total CC admission for both direct and those who would have needed transfer to have a critical procedure	Sum of the above
Straight to MTC CCLOS	Average (mean) CCLOS for patients who went straight to MTC	Uses IF formula to highlight the relevant triage steps and then AVERAGE formula to average those with a CCLOS >0 days. Builds in an IFERROR formula to display an 'N/A' message of there are no CC patients to divide by (as opposed to showing the standard error message i.e. #DIV/0! When trying to divide by zero.
TU Secondary Transfers CCLOS	Mean CCLOS admission for those who would have not gone direct to MTC but went on to have critical procedure and therefore would have required secondary transfer	Uses IF formula that identifies the patients who would no longer trigger any activation if the selected step were removed and within them calculates CCLOS as per formula above
Straight to MTC CC Bed Days	CC bed days for patients who went to MTC directly (CCLOS x no. patients)	SUM of SUMIF formula for the CCLOS column in the activated patients. Multiplied by scaling factor.
TU Secondary Transfers CC Bed Days	CC bed days for those who would have not gone direct to MTC but went on to have critical procedure and therefore would have required secondary transfer	Uses IF formula that identifies the patients who would no longer trigger any activation if the selected step were removed and within them calculates CC bed days as per formula above

MTC CC Bed Days including Secondary Transfers	Total CC bed days for both direct and those who would have needed transfer to have a critical procedure	Sum of the above
Straight to MTC HLOS	Average (mean) LOS for patients who went straight to MTC	Uses IF formula to highlight the relevant triage steps and then AVERAGE formula to average HLOS column. Builds in an IFERROR formula to display an 'N/A' message of there are no patients to divide by (as opposed to showing the standard error message i.e. #DIV/0! When trying to divide by zero.
TU Secondary Transfer HLOS	Mean LOS admission for those who would have not gone direct to MTC but went on to have critical procedure and therefore would have required secondary transfer	Uses IF formula that identifies the patients who would no longer trigger any activation if the selected step were removed and within them calculates LOS as per formula above
Straight to MTC Hospital Bed Days	Total bed days for patients who went to MTC directly (LOS x no. patients)	SUM of SUMIF formula for the LOS column in the activated patients. Multiplied by scaling factor.
TU Secondary Transfer Hosp Bed Days	Total bed days for those who would have not gone direct to MTC but went on to have critical procedure and therefore would have required secondary transfer	SUM(SUMIF…) formula that identifies the patients who would no longer trigger any activation if the selected step were removed and within them calculates bed days as per formula above
MTC Bed Days including Secondary Transfer	Total bed days for both direct and those who would have needed transfer to have a critical procedure	Sum of the above
Straight to MTC Median ISS	**Median** ISS for patients who went straight to MTC.	Uses IF formula to highlight the relevant triage steps and then MEDIAN formula to average ISS column. Builds in an IFERROR formula to display an 'N/A' message of there are no patients to divide by (as opposed to showing the standard error message i.e. #DIV/0! When trying to divide by zero.
TU Secondary Transfer Median ISS	Median ISS for those who would have not gone direct to MTC but went on to have critical procedure and therefore would have required secondary transfer	Uses IF formula that identifies the patients who would no longer trigger any activation if the selected step were removed and within them calculates ISS as per formula above
Straight to MTC ISS>15 Patients (n)	Total ISS>15 patients who went to MTC directly	SUM of COUNTIF formula for the ISS>15 column in the activated patients. Multiplied by scaling factor.
TU Secondary Transfer ISS>15 Patients (n)	Total bed days for those who would have not gone direct to MTC but went on to have critical procedure and therefore would have required secondary transfer	SUM(COUNTIF…) formula that identifies the patients who would no longer trigger any activation if the selected step were removed and within them calculates total ISS>15 as per formula above
MTC ISS>15 Patients Including	Total bed days for both direct and those who would have needed transfer to have a critical procedure	Sum of the above

Secondary Transfer		
MTC Admissions Saved	How many MTC admissions are saved (considering the secondary transfers to MTC)	Subtracts the total going straight to MTC from the overall n, but then further subtracts the patients who end up coming to MTC as a secondary transfer (those that needed surgery)
Primary LAS Bypasses avoided	How many direct MTC trips were made by LAS. Doesn’t consider the secondary transfers	Subtracts the total going straight to MTC from the overall n
Mortality MTC	% mortality at MTCs	Divide total MTC mortality by MTC admissions. IFERROR formula used to give ”0.0%” if division error occurs
Mortality TU	Mortality rate among the TU patients (not including patients transferred to MTC) as a percentage of those TU patients	Mortality difference x scaling factor divided by n MTC admissions saved
Overall Mortality (Renamed Original Mortality)	Seems to remain at the same 7.9% mortality in the baseline data. Perhaps served for comparison	Takes the current/new MTC mortality and adds any difference back to maintain the same 7.9%
Secondary Transfers	No. of patients transferred for critical procedures	Scaling factor x baseline no. sec transfers (n=263) minus the no. of MTC critical procedures
Straight to MTC CC Admissions saved	Direct admission CC admissions saved as a result step removal (not including subsequent secondary transfers to CC)	Scaling factor x baseline no. MTC CC admissions (n=382) minus the no. of MTC CC admissions
CC Admissions Saved With Secondary Transfers included	Total no. direct CC admissions saved, considering the triage negative patients transferred to MTC CC	Scaling factor x baseline no. MTC CC admissions (n=382) minus the no. of MTC CC admissions and then subtracting the secondary transfer CC admissions
Straight to MTC CC Bed Days Saved	Direct admission CC bed days saved as a result of step removal (not including subsequent secondary transfers to CC)	Scaling factor x baseline no. MTC CC bed days (n=3638) minus the no. of MTC CC bed days
CC Bed Days Saved With Secondary Transfers included	Total no. CC bed days saved as a result of step removal considering the triage negative patients transferred to MTC CC	Scaling factor x baseline no. MTC CC bed days (n=3638) minus the no. of MTC CC admissions and then subtracting the secondary transfer CC bed days
Straight to MTC Hosp Bed Days Saved	Direct admission Hosp bed days saved as a result of step removal (not including subsequent secondary transfers)	Scaling factor x baseline no. MTC Hosp bed days (n=21906) minus the no. of MTC Hosp bed days
Hosp Bed Days Saved With Secondary Transfers included	Total no. Hosp bed days saved as a result of step removal considering the triage negative patients transferred to MTC	Scaling factor x baseline no. MTC Hosp bed days (n=21906) minus the no. of MTC Hosp admissions and then subtracting the secondary transfer Hosp bed days

Appendix 3: Patients who die at TU following TuTOR 1 implementation (based on original n=1157 dataset)

Triage step	**Age**	**GCS**	**ISS**	**Mechanism**	**Injuries**	**Surgery (not within 12 hrs)**	**CCLOS**	**HLOS**
2D	94	9	24	Fall > 2m	Skull #, SAH, maxfax #,upper limb #	n/a	0	29
2D	97	15	19	Fall <2m	NoF#, pelvic #, cerebral contusion	n/a	0	15
2E	59	14	20	RTC	Lung contusion, PTX, HTX, rib #, C/T spine #s	Wound suture	9	9
2F	68	15	29	Fall >2m	SDH, cerebral oedema, multiple c-spine #s	ICP monitoring	18	18
2F	93	13	30	Fall <2m	Maxfax #, cervical cord contusion	n/a	0	4
2F	82	15	25	Fall <2m	Vertebral artery laceration, cord contusion	n/a	0	7
2G	82	13	18	Fall <2m	SAH, tib-fib#	ORIF, skin graft	0	15
4A	78	15	16	Fall <2m	Lung contusion, HTX, rib #, thoracic vert. #	n/a	5	6
4A	89	14	14	Fall >2m	Maxfax #, cervical cord contusion, c-spine #	n/a	0	2
4A	96	15	22	Fall < 2m	SAH, rib #, maxfax #	n/a	0	6
4A	94	15	20	Fall < 2m	EDH, cerebral oedema, thoracic spine #	n/a	0	16
4A	86	15	9	Fall < 2m	c-spine #s	n/a	0	2

CCLOS = Critical Care length of stay
HLOS= Hospital length of stay

Appendix 4: Implementation of new London triage tool

NHS
London
Operational Delivery Networks

London Major Trauma System

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18th March 2020

Maintaining Major Trauma Capacity during Coronavirus Pandemic
London Trauma Steering Group

Dear all

I hope you are all keeping well, and stay well, during this episode, which will undoubtedly stretch us and our teams to the limits, mentally and physically, over the coming weeks. While there is naturally major focus on the management of coronavirus patients at the moment, the biggest impact on mortality and morbidity is likely to be in those patients unable to access specialist care because of lack of resources. This is especially true of major trauma patients, who are (still usually) young and have full productive lives to lead, and are often the principle source of financial security for their families. London and the South East is going to take the brunt of the pandemic. As of last night, one third of all ICU beds in the capital were occupied by patients with known or suspected COVID.

We need to maintain the ability for the London Major Trauma System to look after its injured population as best we can during this pandemic, using the principles of doing “the most for the most” that we are used to applying during major incidents and mass casualty events. As in these events, we depend on Trauma Units to manage the surge, both temporarily and geographically. The difference in this event of course is that every hospital will be in a similar state, so we need to use the trauma networks to support each other. We are expecting about a 35-40% drop in trauma cases based on experience from Italy, Hong Kong & Washington state, which will help, but we still need to act now.

In order to do this, we are going to have to make some rapid changes to how we work over the next few days, and have some contingencies for if/when we become overwhelmed in the coming weeks. We have outlined the big items below. Many of these are extensions of proposals that we have been working up anyway over the last 12-18 months in recognition of the imbalance that currently exists across the trauma system and recognise the capability of the trauma units to manage major trauma effectively (as you already do for over half of the ISS>15 trauma patients across the system). We were planning on bringing these in after the usual consultations, local testing etc. Now we need to bring them in at pace, and iteratively hone out the problems as we go.

The principles of the system changes for the COVID pandemic response are to maintain existing levels of trauma survival, and minimize disability, while maximising resource availability for the COVID response (especially critical care capacity, and especially capacity at hospitals with single ICUs).

We are therefore planning to institute the following changes over the next few days:

1. Major Trauma Centres and Networks will enact plans to provide rapid and easy virtual consults for all Trauma Units across the System, with the aim of keeping as many patients without life threatening injuries or requiring critical care in the Trauma Units. This will be organised differently within each network, but may include actions like daily virtual rounds, assisted access to specialty opinions, radiology reviews etc.

2. To modify the trauma triage tool to make it more specific for those with life threatening injuries or who require rapid specialist surgery. We expect this to add an additional 5 trauma calls per London TU during the pandemic response (See appendix 1 below).

3. For each MTC and TU ensure that ceilings of care are assessed and clear for each patient, and are aligned with decision making that is occurring across your hospital and across the system.

4. To move to less invasive, delayed or conservative approaches to the management of some injuries as able. See specialty advice which is being developed as well as specific local and network arrangements. https://www.england.nhs.uk/coronavirus/secondary-care/other-resources/specialty-guides/

5. To maintain outflows across the system to allow continued receiving capability at all centres and units.

A lot of work is being done centrally at NHS England, and at London Region especially to support these measures and the maintenance of some degree of all specialty services. It is likely that these measures we're proposing do not go far enough, and we are working on contingency planning for this eventuality now, including the possibility of closing one or more major trauma centres, but we need to do all we can to keep all four open for now.

We would like to hold a video/teleconference to discuss this and allow you to bring comments and ideas to us, with a view to beginning to implement these changes from next Monday (23rd March) so we have a little bit of time to test them before the peak of COVID hits us. ***The provisional date/time for the teleconference is this Friday at 1pm.*** We'll send out joining details shortly.

Thank you for everything,

Karim
07703190545

(See details of trauma triage tool changes below)

LONDON MAJOR TRAUMA SYSTEM / LONDON AMBULANCE SERVICE

Triage Tool modification for COVID Pandemic Response

We are proposing to change the London Triage Tool (Figure 1) to only invoke primary bypass to major trauma centres if the patient has:

Step 1:
1A-1C: Critical derangements in physiology / GCS

Step 2:
2A: Severe chest wall injury with respiratory compromise2B: Traumatic amputation
2C: Penetrating neck or torso injury.
2E: Spinal trauma with quadriplegia/paraplegia.2H-J: Burns criteria

All other cases will be initially triaged to a trauma unit for management.

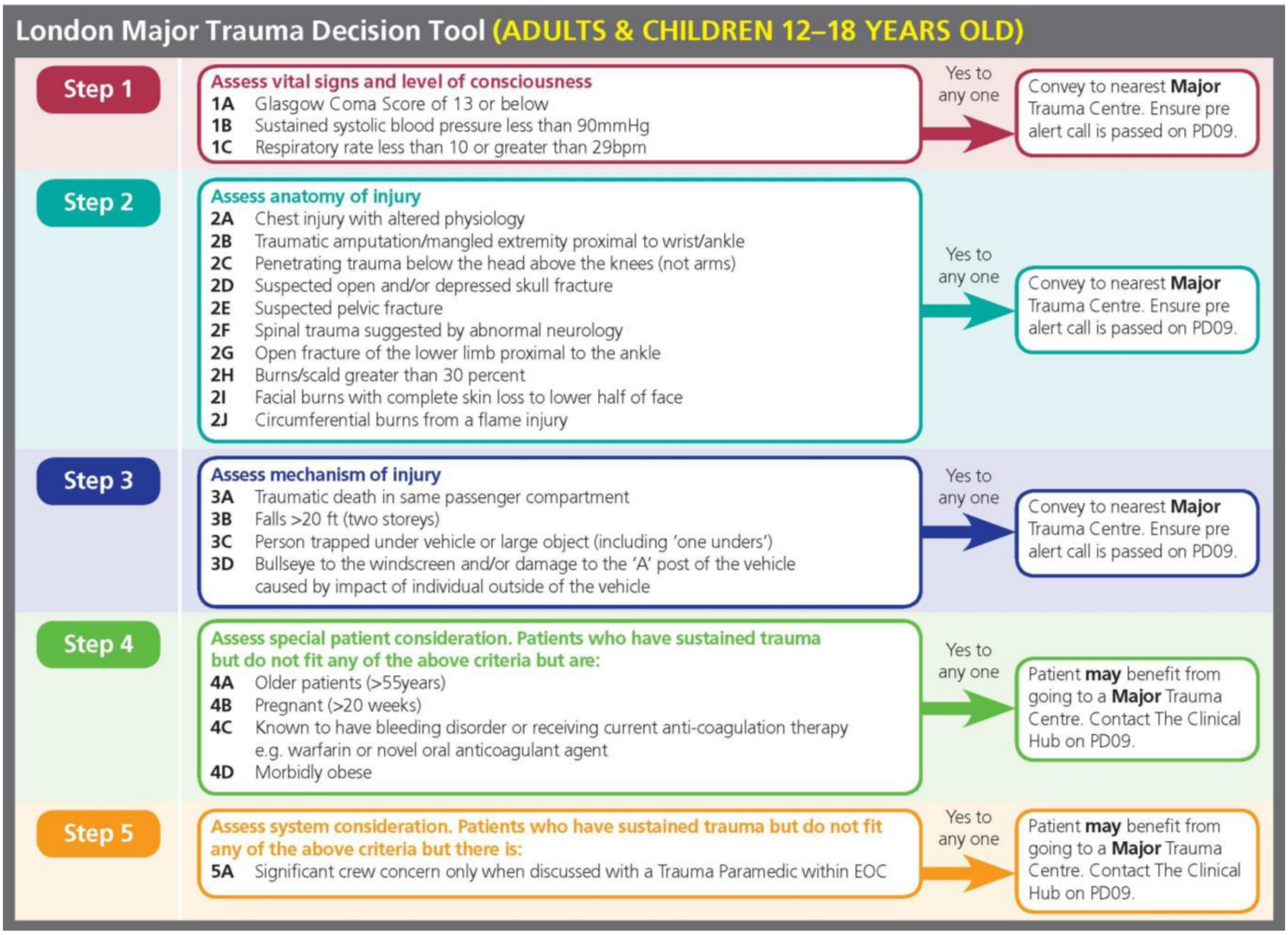
This is very close to a version of the tool we have been developing based on a collaborative research project with London Ambulance Service over the last 2 years, looking at the performance of each step in identifying patients likely to die or require urgent intervention (see summary data in Figure 2) − and which we were planning to test in a step wise implementation later this year.

This change will be supported by increased telephone and virtual support for patients in ED and on the wards at Trauma units by the Major Trauma Centres and Networks; and we are looking to see how we can provide surgical teams and HEMS retrieval support for any patient undertriaged at the centre where secondary transfer to the MTCcan’t happen within an appropriate timeframe.

For now, these changes will apply only to the London Triage Tool. The proposed changes will bring London closer to triage tools used by East of England and other areas, and we will be assessing the impact of the changes and whetherwe need to work with other ambulance services to enact changes as we proceed.

Our data modelling suggests that under normal workload, this would result in an extra 7 major trauma patients per month for each trauma unit (equivalent to 2576 patients across London for the year). With 30%-40% reduction in trauma workload we expect this to be an additional 4-5 cases per month, so hopefully should not induce a significantadditional burden on units individually.

Trauma Triage Tool



London Major Trauma Decision Tool (ADULTS & CHILDREN 12–18 YEARS OLD)

Step 1

Assess vital signs and level of consciousness

- **1A** Glasgow Coma Score of 13 or below
- **1B** Sustained systolic blood pressure less than 90mmHg
- **1C** Respiratory rate less than 10 or greater than 29bpm

Yes to any one → Convey to nearest **Major** Trauma Centre. Ensure pre alert call is passed on PD09.

Step 2

Assess anatomy of injury

- **2A** Chest injury with altered physiology
- **2B** Traumatic amputation/mangled extremity proximal to wrist/ankle
- **2C** Penetrating trauma below the head above the knees (not arms)
- **2D** Suspected open and/or depressed skull fracture
- **2E** Suspected pelvic fracture
- **2F** Spinal trauma suggested by abnormal neurology
- **2G** Open fracture of the lower limb proximal to the ankle
- **2H** Burns/scald greater than 30 percent
- **2I** Facial burns with complete skin loss to lower half of face
- **2J** Circumferential burns from a flame injury

Yes to any one → Convey to nearest **Major** Trauma Centre. Ensure pre alert call is passed on PD09.

Step 3

Assess mechanism of injury

- **3A** Traumatic death in same passenger compartment
- **3B** Falls >20 ft (two storeys)
- **3C** Person trapped under vehicle or large object (including 'one unders')
- **3D** Bullseye to the windscreen and/or damage to the 'A' post of the vehicle caused by impact of individual outside of the vehicle

Yes to any one → Convey to nearest **Major** Trauma Centre. Ensure pre alert call is passed on PD09.

Step 4

Assess special patient consideration. Patients who have sustained trauma but do not fit any of the above criteria but are:

- **4A** Older patients (>55years)
- **4B** Pregnant (>20 weeks)
- **4C** Known to have bleeding disorder or receiving current anti-coagulation therapy e.g. warfarin or novel oral anticoagulant agent
- **4D** Morbidly obese

Yes to any one → Patient **may** benefit from going to a **Major** Trauma Centre. Contact The Clinical Hub on PD09.

Step 5

Assess system consideration. Patients who have sustained trauma but do not fit any of the above criteria but there is:

- **5A** Significant crew concern only when discussed with a Trauma Paramedic within EOC

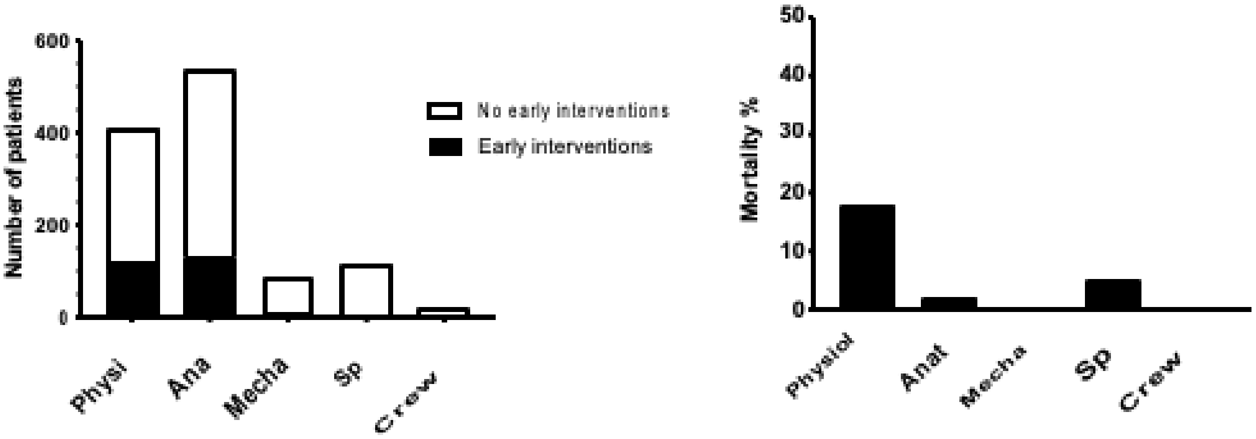
Yes to any one → Patient **may** benefit from going to a **Major** Trauma Centre. Contact The Clinical Hub on PD09.

London Trauma Triage Tool Performance (from TUTOR Study)

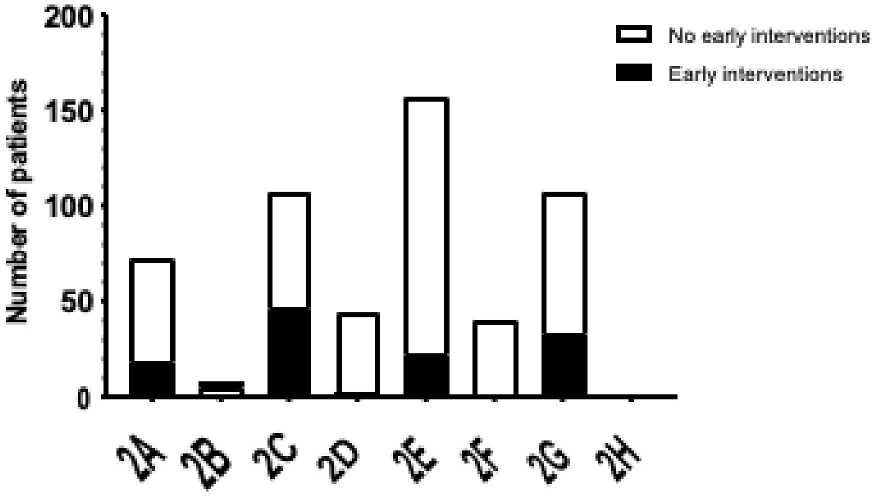
Based on 2 years of data from London Trauma System

Overall Performance

Overall Performance



Step 2 Performance



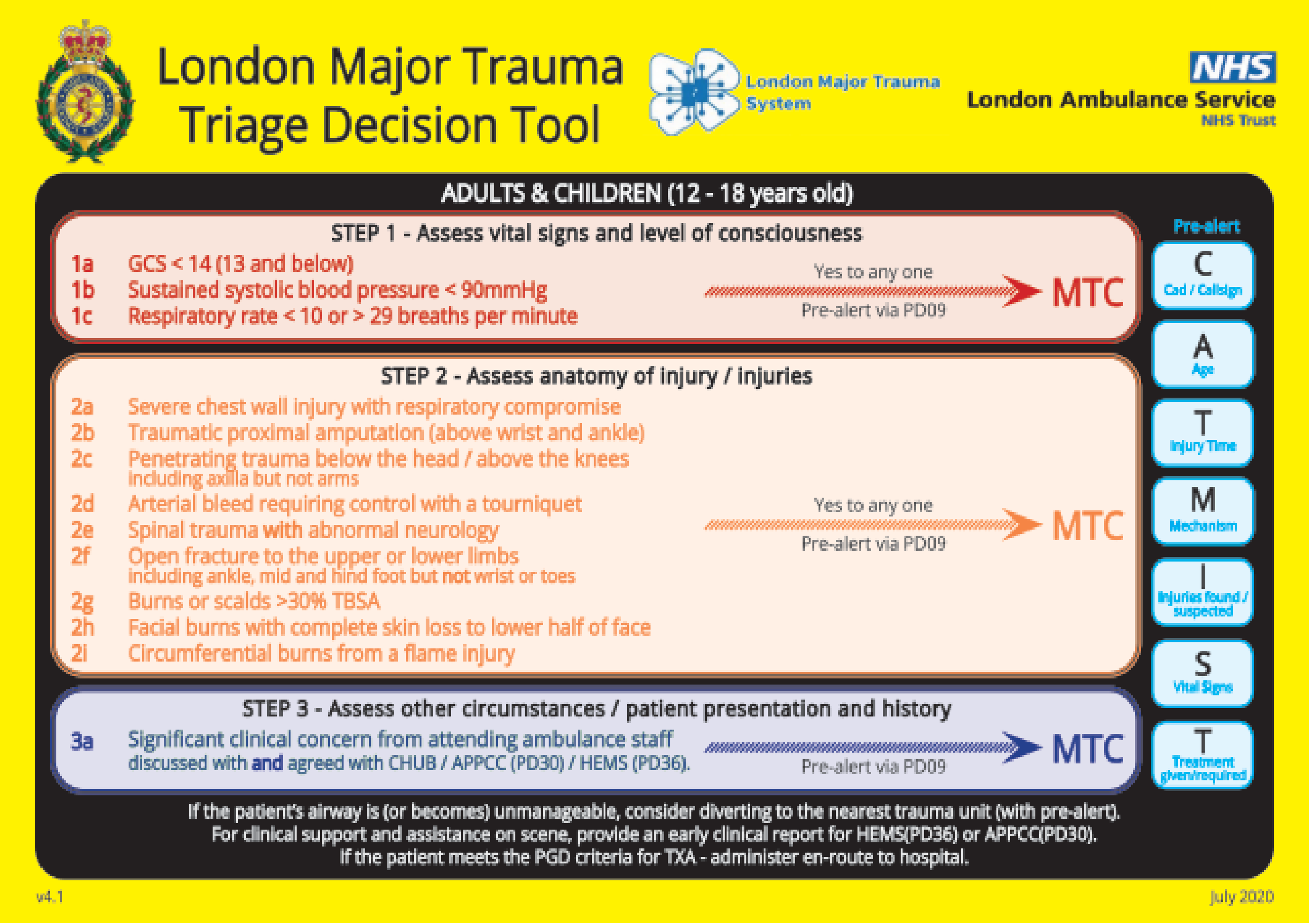
Step 4 (Age)

Age >55	**MTC (Step 4a)**	**TU**
n	**101**	**6430**
30-day mortality	5 (5%)	435 (7%)
Early intervention	2 (2%)	151 (2%)
ICU LOS (days)	2 (1-6)	3 (1-6)
Hospital LOS (days)	11 (6-22)	11 (6-20)

Multivariable analysis of factors associated with ***30-day mortality*** *in* ***patients >55yrs***

	Age >55		**Age 55-69**		**Age 70+**	
n	6531		1467		5064	
	OR (95% CI)	***p value***	**OR (95% CI)**	***p value***	**OR (95% CI)**	***p value***
Admission Age	1.09 (1.07-1.10)	<0.001	0.99 (0.88-1.12)	0.87	1.08 (1.06-1.10)	<0.001
Gender (Male)	1.28 (1.03-1.61)	0.03	0.44 (0.17-1.17)	0.10	1.36 (1.08-1.71)	0.01
Admission GCS	0.73 (0.70-0.77)	<0.001	0.88 (0.77-1.01)	0.07	0.71 (0.66-0.75)	<0.001
ISS	1.05 (1.04-1.07)	<0.001	1.02 (0.96-1.09)	0.58	1.05 (1.04-1.07)	<0.001
ICU admission	4.20 (2.76-6.38)	<0.001	30.21 (10.64-85.79)	<0.001	3.15 (1.94-5.14)	<0.001
Level of Care (MTC)	0.59 (0.23-1.54)	0.28	0.00 (0.00-?)	0.998	0.67 (0.03-1.78)	0.42

Appendix 5: New London Triage Tool (July 2020)



London Major Trauma Triage Decision Tool

London Major Trauma System

NHS London Ambulance Service NHS Trust

ADULTS & CHILDREN (12 - 18 years old)

STEP 1 - Assess vital signs and level of consciousness

1a GCS < 14 (13 and below)
1b Sustained systolic blood pressure < 90mmHg
1c Respiratory rate < 10 or > 29 breaths per minute

Yes to any one → MTC
Pre-alert via PD09

STEP 2 - Assess anatomy of injury / injuries

2a Severe chest wall injury with respiratory compromise
2b Traumatic proximal amputation (above wrist and ankle)
2c Penetrating trauma below the head / above the knees
including axilla but not arms
2d Arterial bleed requiring control with a tourniquet
2e Spinal trauma with abnormal neurology
2f Open fracture to the upper or lower limbs
including ankle, mid and hind foot but not wrist or toes
2g Burns or scalds >30% TBSA
2h Facial burns with complete skin loss to lower half of face
2i Circumferential burns from a flame injury

Yes to any one → MTC
Pre-alert via PD09

STEP 3 - Assess other circumstances / patient presentation and history

3a Significant clinical concern from attending ambulance staff
discussed with **and** agreed with CHUB / APPCC (PD30) / HEMS (PD36).

→ MTC
Pre-alert via PD09

Pre-alert

C Cad / Callsign
A Age
T Injury Time
M Mechanism
I Injuries found / suspected
S Vital Signs
T Treatment given/required

If the patient's airway is (or becomes) unmanageable, consider diverting to the nearest trauma unit (with pre-alert).
For clinical support and assistance on scene, provide an early clinical report for HEMS(PD36) or APPCC(PD30).
If the patient meets the PGD criteria for TXA - administer en-route to hospital.

v4.1 July 2020

Appendix 6: Data presented alongside letter (Appendix 4) to justify triage tool change

LMTS Triage Tool modification for major pandemic

Step 1:
1A-1C: Critical derangements in physiology / GCS

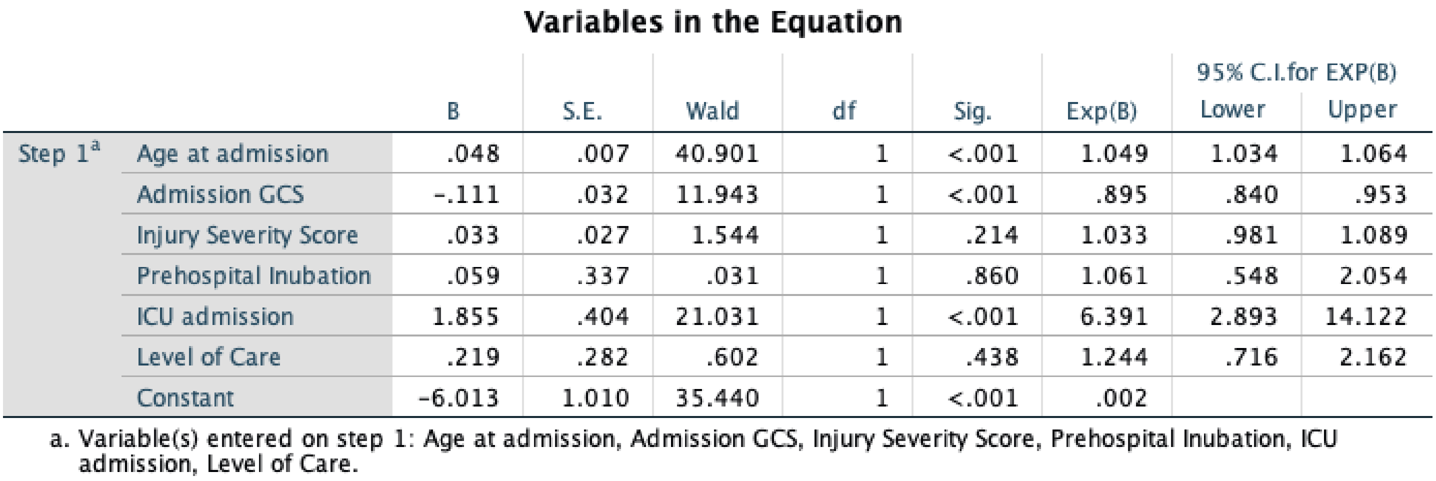
Step 2:
2A: Severe chest wall injury with respiratory compromise
2B: Traumatic amputation
2C: Penetrating neck or torso injury.
2F: Spinal trauma with quadriplegia/paraplegia.
2H-J: Burns criteria

All other cases will be initially triaged to a trauma unit for management.

STEP REMOVED	DIRECT MTC ADMISSIONS	PRIMARY LAS BYPASSES AVOIDED	SECONDARY TRANSFERS	ADMISSIONS FOR 'NON-CRITICAL INTERVENTION' SAVED	MTC MORTALITY %	TU TRANSFER MORTALITY %	TU REMAINER MORTALITY %	MEDIAN ISS MTC	ISS >15 % (DIRECT AND TRANSFER)
REFERENCE	7000	n/a	n/a	n/a	7.9	n/a	n/a	15	56
COVID TOOL	3872	3128	430	2698	12.7	0	2.2	19	71

STEP REMOVED	DIRECT MTC CC ADMISSIONS SAVED	TOTAL CC ADMISSIONS SAVED	DIRECT MTC CC BED DAYS SAVED	TOTAL CC BED DAYS SAVED	DIRECT MTC HOSP BED DAYS SAVED	TOTAL HOSP BED DAYS SAVED
REFERENCE	n/a	n/a	n/a	n/a	n/a	n/a
COVID TOOL	387	284	2753	2160	49563	40590

Appendix 7: Full regression output data for CONS and NSC TBI patients from Study 1 (all age groups)

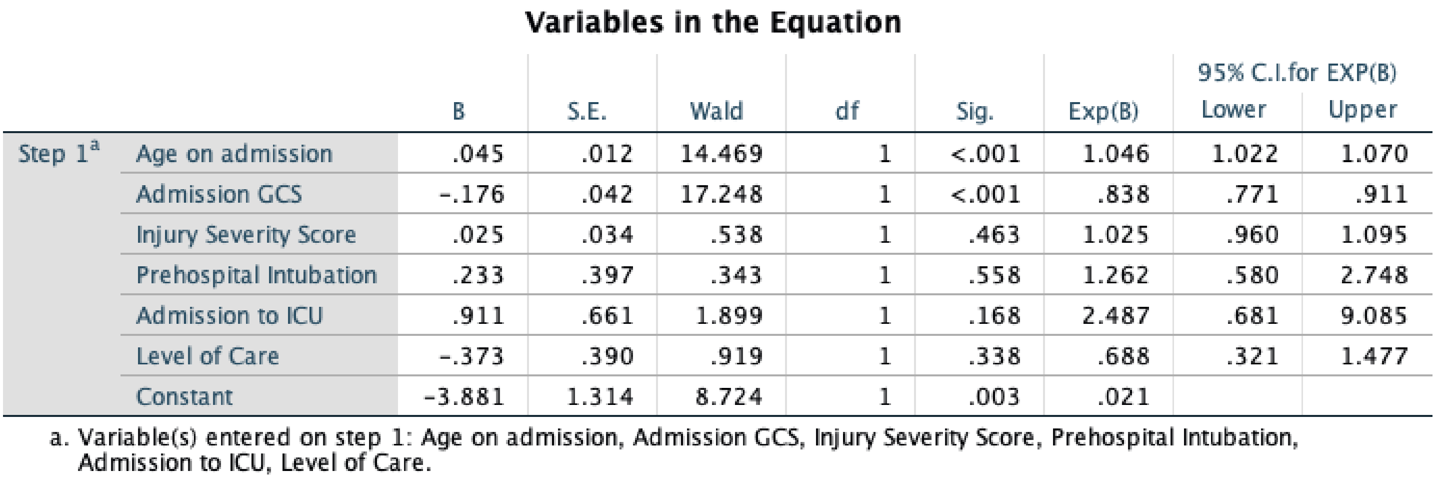


Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	Age at admission	.048	.007	40.901	1	<.001	1.049	1.034	1.064
	Admission GCS	-.111	.032	11.943	1	<.001	.895	.840	.953
	Injury Severity Score	.033	.027	1.544	1	.214	1.033	.981	1.089
	Prehospital Inubation	.059	.337	.031	1	.860	1.061	.548	2.054
	ICU admission	1.855	.404	21.031	1	<.001	6.391	2.893	14.122
	Level of Care	.219	.282	.602	1	.438	1.244	.716	2.162
	Constant	-6.013	1.010	35.440	1	<.001	.002		

a. Variable(s) entered on step 1: Age at admission, Admission GCS, Injury Severity Score, Prehospital Inubation, ICU admission, Level of Care.

30-day mortality binary logistic regression output table for NSC patients all ages

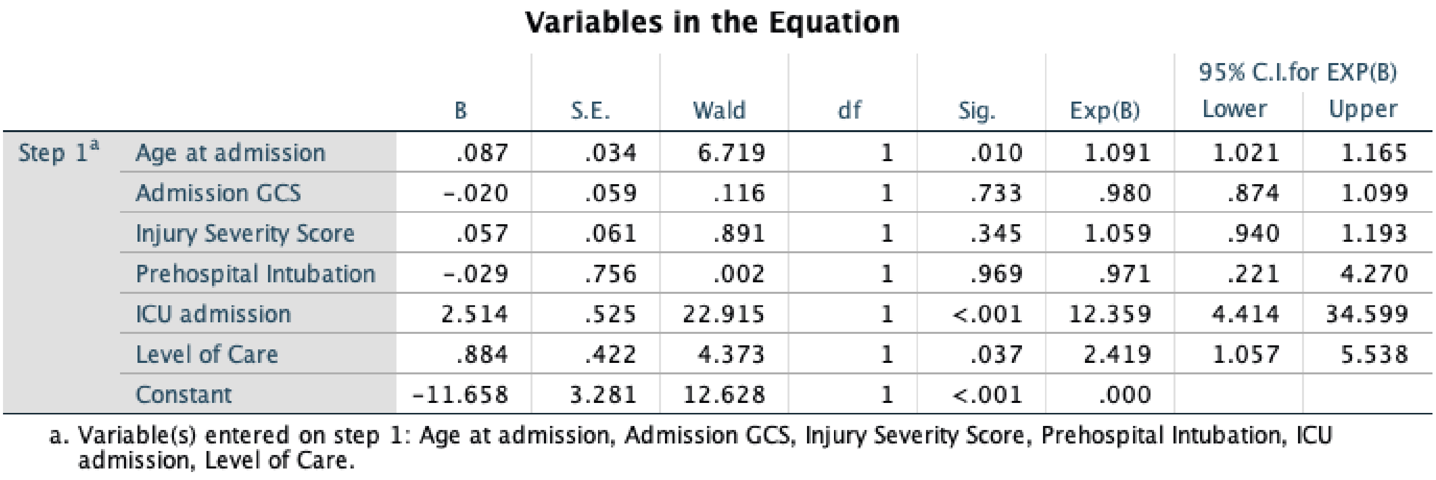


Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	Age on admission	.045	.012	14.469	1	<.001	1.046	1.022	1.070
	Admission GCS	-.176	.042	17.248	1	<.001	.838	.771	.911
	Injury Severity Score	.025	.034	.538	1	.463	1.025	.960	1.095
	Prehospital Intubation	.233	.397	.343	1	.558	1.262	.580	2.748
	Admission to ICU	.911	.661	1.899	1	.168	2.487	.681	9.085
	Level of Care	-.373	.390	.919	1	.338	.688	.321	1.477
	Constant	-3.881	1.314	8.724	1	.003	.021		

a. Variable(s) entered on step 1: Age on admission, Admission GCS, Injury Severity Score, Prehospital Intubation, Admission to ICU, Level of Care.

30-day mortality binary logistic regression output table for NSC patients ages 16-69

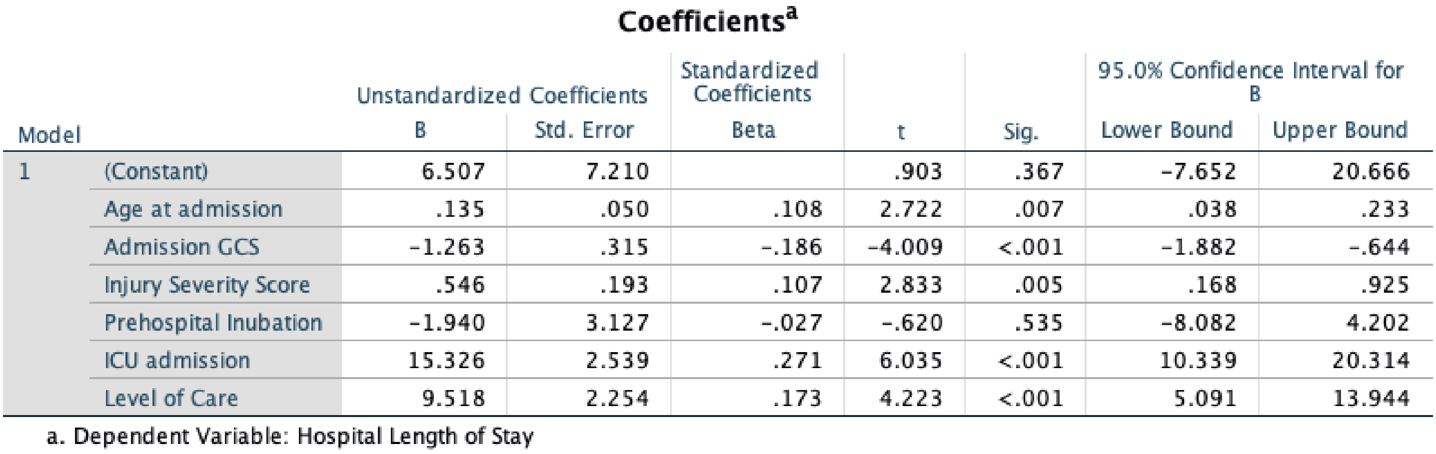


Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	Age at admission	.087	.034	6.719	1	.010	1.091	1.021	1.165
	Admission GCS	-.020	.059	.116	1	.733	.980	.874	1.099
	Injury Severity Score	.057	.061	.891	1	.345	1.059	.940	1.193
	Prehospital Intubation	-.029	.756	.002	1	.969	.971	.221	4.270
	ICU admission	2.514	.525	22.915	1	<.001	12.359	4.414	34.599
	Level of Care	.884	.422	4.373	1	.037	2.419	1.057	5.538
	Constant	-11.658	3.281	12.628	1	<.001	.000		

a. Variable(s) entered on step 1: Age at admission, Admission GCS, Injury Severity Score, Prehospital Intubation, ICU admission, Level of Care.

30-day mortality binary logistic regression output table for NSC patients ages 70 and over

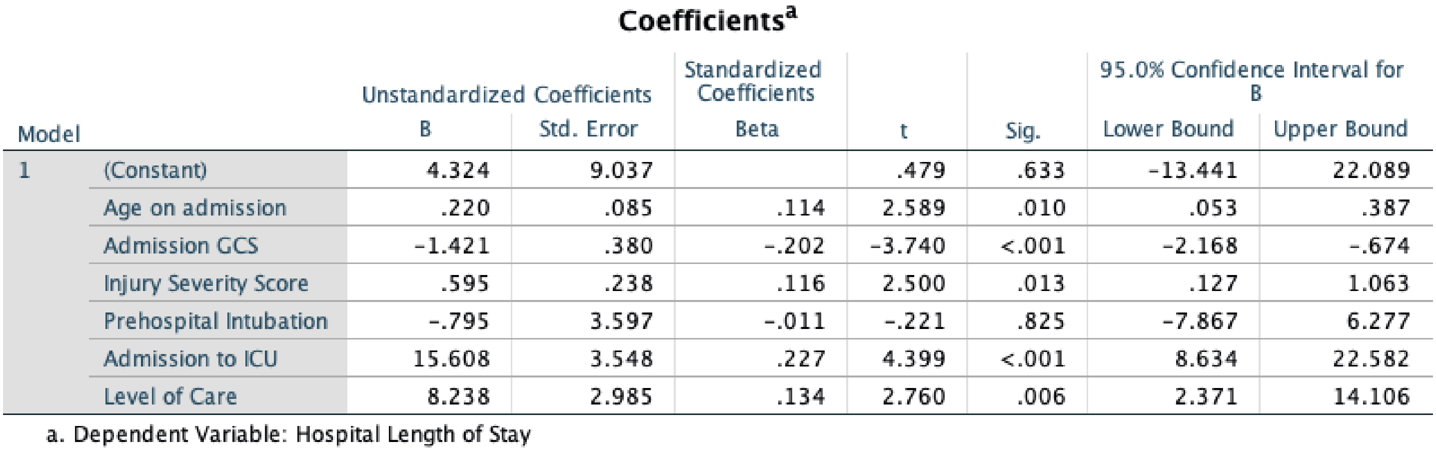


Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	6.507	7.210		.903	.367	-7.652	20.666
	Age at admission	.135	.050	.108	2.722	.007	.038	.233
	Admission GCS	-1.263	.315	-.186	-4.009	<.001	-1.882	-.644
	Injury Severity Score	.546	.193	.107	2.833	.005	.168	.925
	Prehospital Inubation	-1.940	3.127	-.027	-.620	.535	-8.082	4.202
	ICU admission	15.326	2.539	.271	6.035	<.001	10.339	20.314
	Level of Care	9.518	2.254	.173	4.223	<.001	5.091	13.944

a. Dependent Variable: Hospital Length of Stay

Hospital LOS linear regression output table for NSC patients all ages

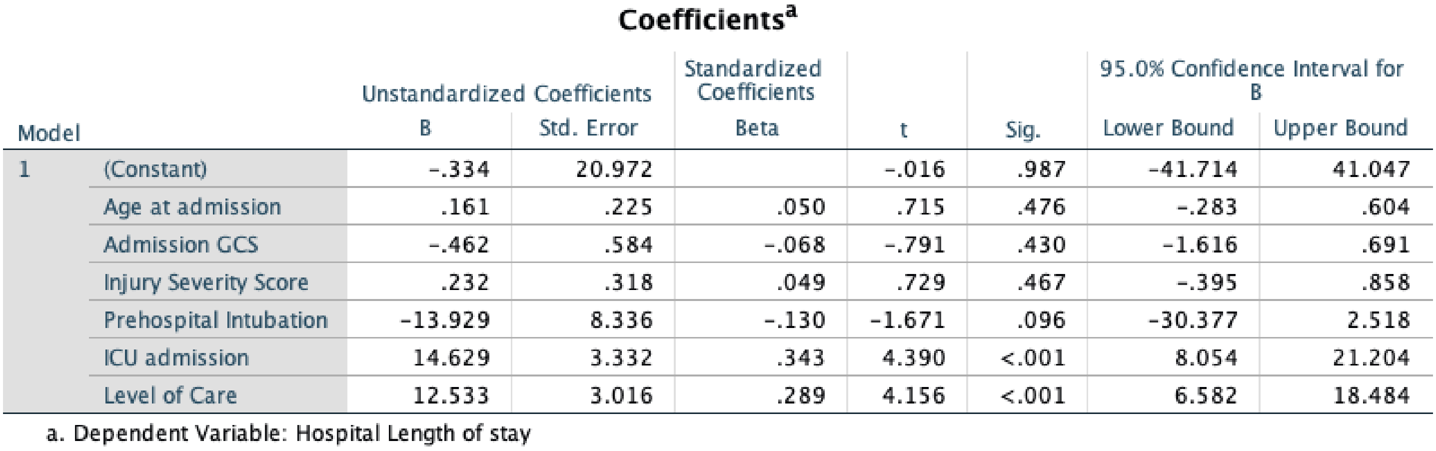


Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	4.324	9.037		.479	.633	-13.441	22.089
	Age on admission	.220	.085	.114	2.589	.010	.053	.387
	Admission GCS	-1.421	.380	-.202	-3.740	<.001	-2.168	-.674
	Injury Severity Score	.595	.238	.116	2.500	.013	.127	1.063
	Prehospital Intubation	-.795	3.597	-.011	-.221	.825	-7.867	6.277
	Admission to ICU	15.608	3.548	.227	4.399	<.001	8.634	22.582
	Level of Care	8.238	2.985	.134	2.760	.006	2.371	14.106

a. Dependent Variable: Hospital Length of Stay

Hospital LOS linear regression output table for NSC patients ages 16-69

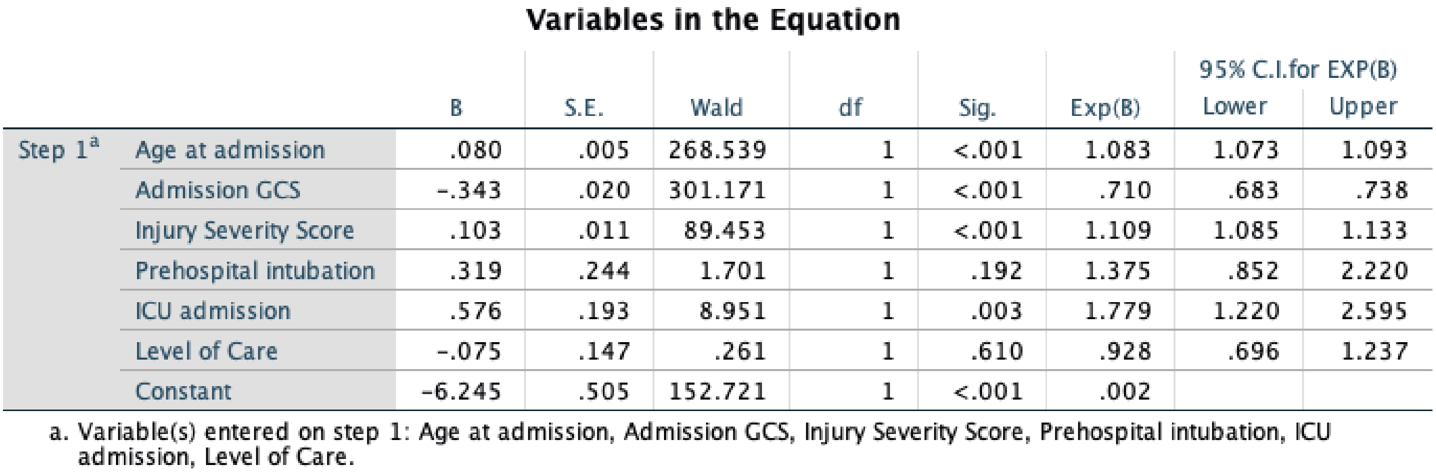


Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-.334	20.972		-.016	.987	-41.714	41.047
	Age at admission	.161	.225	.050	.715	.476	-.283	.604
	Admission GCS	-.462	.584	-.068	-.791	.430	-1.616	.691
	Injury Severity Score	.232	.318	.049	.729	.467	-.395	.858
	Prehospital Intubation	-13.929	8.336	-.130	-1.671	.096	-30.377	2.518
	ICU admission	14.629	3.332	.343	4.390	<.001	8.054	21.204
	Level of Care	12.533	3.016	.289	4.156	<.001	6.582	18.484

a. Dependent Variable: Hospital Length of stay

Hospital LOS linear regression output table for NSC patients age 70+

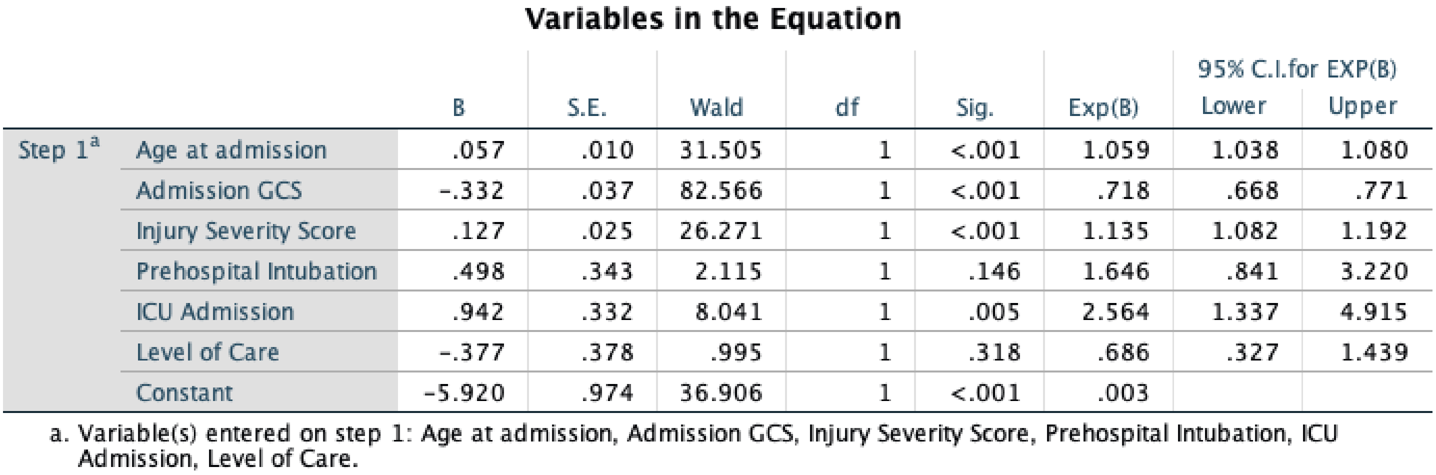


Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	95% C.I.for EXP(B) Upper
Step 1[a]	Age at admission	.080	.005	268.539	1	<.001	1.083	1.073	1.093
	Admission GCS	-.343	.020	301.171	1	<.001	.710	.683	.738
	Injury Severity Score	.103	.011	89.453	1	<.001	1.109	1.085	1.133
	Prehospital intubation	.319	.244	1.701	1	.192	1.375	.852	2.220
	ICU admission	.576	.193	8.951	1	.003	1.779	1.220	2.595
	Level of Care	-.075	.147	.261	1	.610	.928	.696	1.237
	Constant	-6.245	.505	152.721	1	<.001	.002		

a. Variable(s) entered on step 1: Age at admission, Admission GCS, Injury Severity Score, Prehospital intubation, ICU admission, Level of Care.

30-day mortality binary logistic regression output table for CONS patients all ages

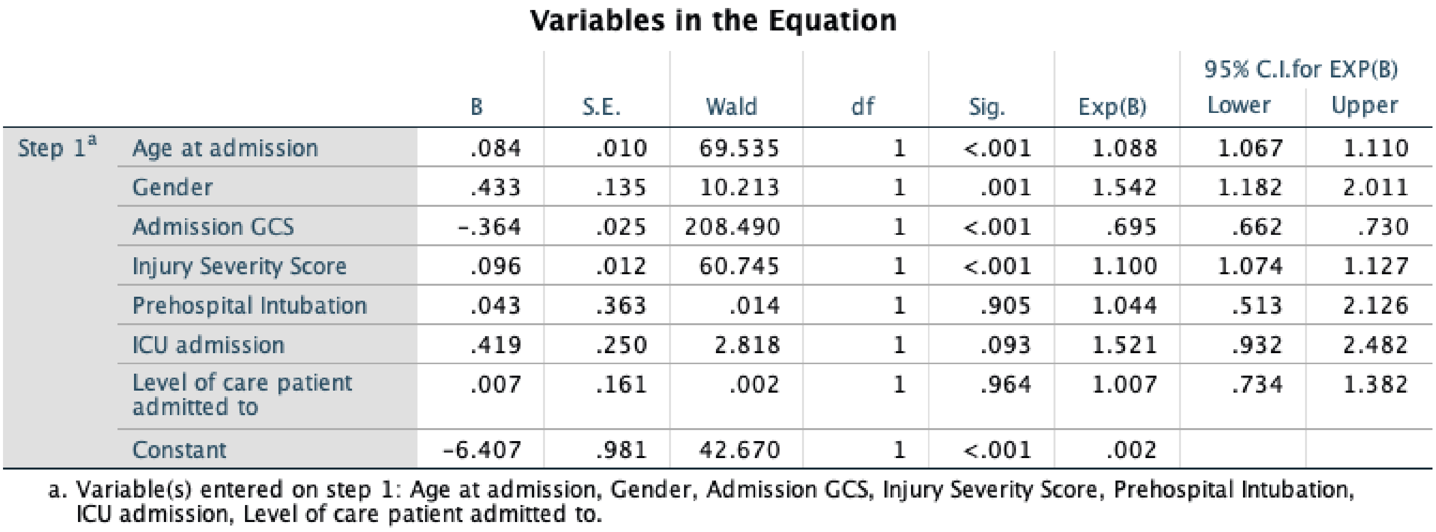


Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	95% C.I.for EXP(B) Upper
Step 1[a]	Age at admission	.057	.010	31.505	1	<.001	1.059	1.038	1.080
	Admission GCS	-.332	.037	82.566	1	<.001	.718	.668	.771
	Injury Severity Score	.127	.025	26.271	1	<.001	1.135	1.082	1.192
	Prehospital Intubation	.498	.343	2.115	1	.146	1.646	.841	3.220
	ICU Admission	.942	.332	8.041	1	.005	2.564	1.337	4.915
	Level of Care	-.377	.378	.995	1	.318	.686	.327	1.439
	Constant	-5.920	.974	36.906	1	<.001	.003		

a. Variable(s) entered on step 1: Age at admission, Admission GCS, Injury Severity Score, Prehospital Intubation, ICU Admission, Level of Care.

30-day mortality binary logistic regression output table for CONS patients ages 16-69

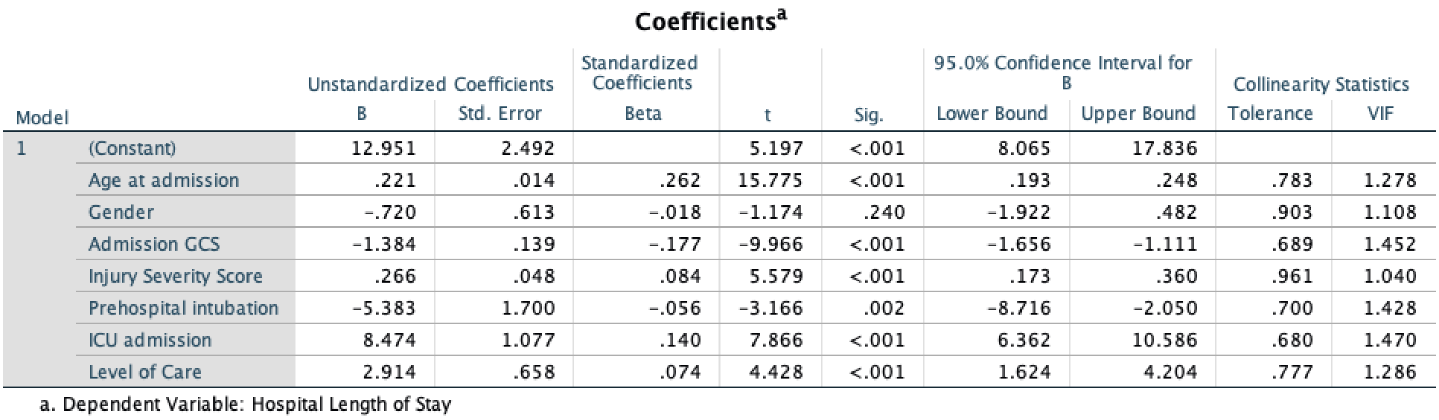


Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	95% C.I.for EXP(B) Upper
Step 1[a]	Age at admission	.084	.010	69.535	1	<.001	1.088	1.067	1.110
	Gender	.433	.135	10.213	1	.001	1.542	1.182	2.011
	Admission GCS	-.364	.025	208.490	1	<.001	.695	.662	.730
	Injury Severity Score	.096	.012	60.745	1	<.001	1.100	1.074	1.127
	Prehospital Intubation	.043	.363	.014	1	.905	1.044	.513	2.126
	ICU admission	.419	.250	2.818	1	.093	1.521	.932	2.482
	Level of care patient admitted to	.007	.161	.002	1	.964	1.007	.734	1.382
	Constant	-6.407	.981	42.670	1	<.001	.002		

a. Variable(s) entered on step 1: Age at admission, Gender, Admission GCS, Injury Severity Score, Prehospital Intubation, ICU admission, Level of care patient admitted to.

30-day mortality binary logistic regression output table for CONS patients ages 70 and over

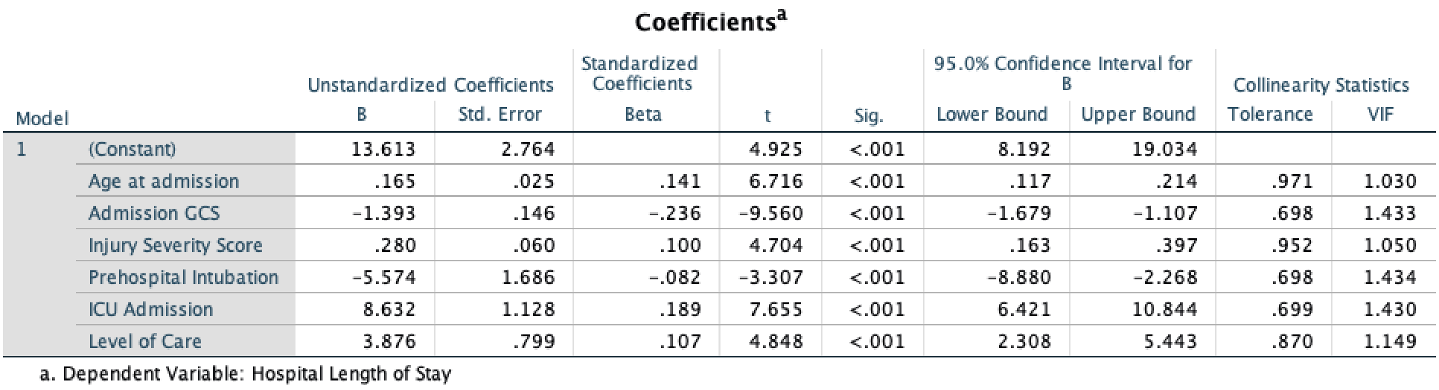


Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	12.951	2.492		5.197	<.001	8.065	17.836		
	Age at admission	.221	.014	.262	15.775	<.001	.193	.248	.783	1.278
	Gender	-.720	.613	-.018	-1.174	.240	-1.922	.482	.903	1.108
	Admission GCS	-1.384	.139	-.177	-9.966	<.001	-1.656	-1.111	.689	1.452
	Injury Severity Score	.266	.048	.084	5.579	<.001	.173	.360	.961	1.040
	Prehospital intubation	-5.383	1.700	-.056	-3.166	.002	-8.716	-2.050	.700	1.428
	ICU admission	8.474	1.077	.140	7.866	<.001	6.362	10.586	.680	1.470
	Level of Care	2.914	.658	.074	4.428	<.001	1.624	4.204	.777	1.286

a. Dependent Variable: Hospital Length of Stay

Hospital LOS linear regression output table for CONS patients all ages

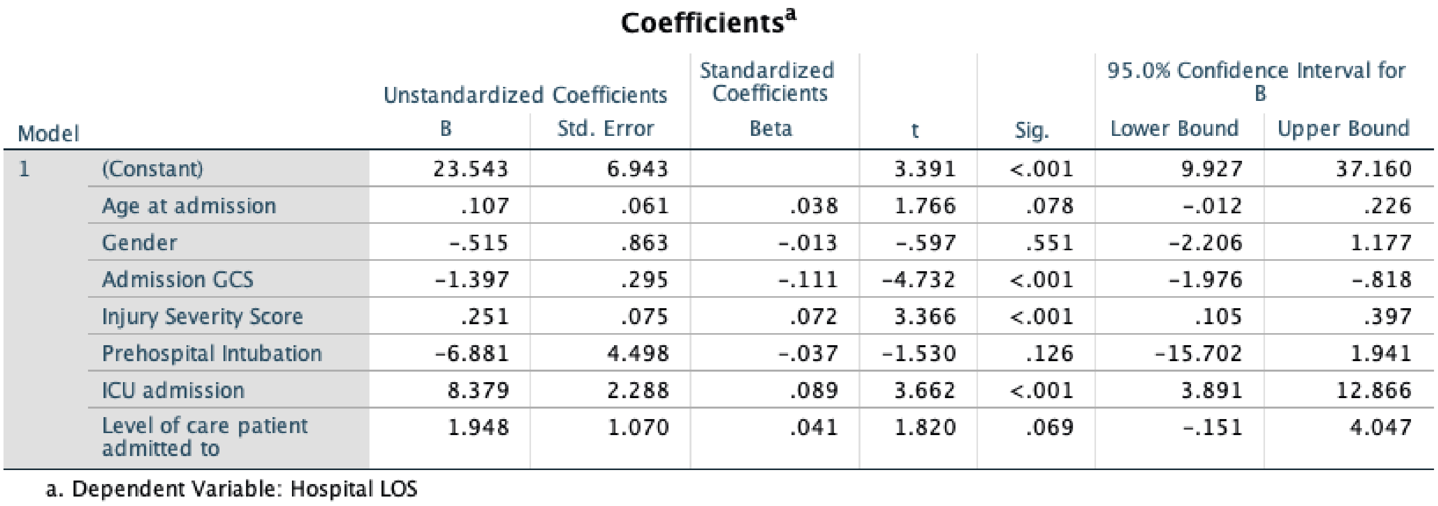


Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	13.613	2.764		4.925	<.001	8.192	19.034		
	Age at admission	.165	.025	.141	6.716	<.001	.117	.214	.971	1.030
	Admission GCS	-1.393	.146	-.236	-9.560	<.001	-1.679	-1.107	.698	1.433
	Injury Severity Score	.280	.060	.100	4.704	<.001	.163	.397	.952	1.050
	Prehospital Intubation	-5.574	1.686	-.082	-3.307	<.001	-8.880	-2.268	.698	1.434
	ICU Admission	8.632	1.128	.189	7.655	<.001	6.421	10.844	.699	1.430
	Level of Care	3.876	.799	.107	4.848	<.001	2.308	5.443	.870	1.149

a. Dependent Variable: Hospital Length of Stay

Hospital LOS linear regression output table for CONS patients ages 16-69



Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	23.543	6.943		3.391	<.001	9.927	37.160
	Age at admission	.107	.061	.038	1.766	.078	-.012	.226
	Gender	-.515	.863	-.013	-.597	.551	-2.206	1.177
	Admission GCS	-1.397	.295	-.111	-4.732	<.001	-1.976	-.818
	Injury Severity Score	.251	.075	.072	3.366	<.001	.105	.397
	Prehospital Intubation	-6.881	4.498	-.037	-1.530	.126	-15.702	1.941
	ICU admission	8.379	2.288	.089	3.662	<.001	3.891	12.866
	Level of care patient admitted to	1.948	1.070	.041	1.820	.069	-.151	4.047

a. Dependent Variable: Hospital LOS

Hospital LOS linear regression output table for CONS patients age 70+