The contemporary evaluation of trauma outcomes

Cameron Scott Palmer

Grad Dip (Clin Epi), B Orth (Hons)

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Department of Epidemiology and Preventive Medicine

Faculty of Medicine, Nursing and Health Sciences

School of Public Health and Preventive Medicine

Monash University

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ABSTRACT

Traumatic injury is a leading cause of death and disability. Trauma may affect any - or multiple - body regions, and result in negligible, impairing, or fatal outcomes. Classifying and summarising injuries to provide overall estimates of injury 'severity' is consequently difficult.

The Abbreviated Injury Scale (AIS) is the de facto global standard for injury classification. AIS codes contain a consensus-derived ordinal severity level for each injury sustained during an injury event. This has enabled the development of summary scores which produce overall injury severity estimates, and hence can describe the severity of a trauma population. Through a variety of applications, AIS-based scores underpin many aspects of modern trauma systems.

The AIS has been periodically updated to reflect contemporaneous changes in trauma diagnosis and management. However, this limits the capacity to compare data over time. Also, there is a continued reliance on potentially outdated or arbitrary uses of the AIS, as well as a focus on the prediction of mortality risk. This has become less relevant in mature trauma systems, with calls to instead attempt to evaluate functional recovery or impairment in the (surviving) majority of trauma patients.

In this thesis, tools for the use and interpretation of AIS-coded data using the most contemporary AIS version were both evaluated and developed. These were applied to both mortality and functional outcome data. At the same time, a secondary aim was to identify principles which would enable the ongoing relevancy of the AIS beyond the current version.

The first two studies in this thesis focused on enabling the comparability of AIS-coded data and AIS-derived scores across AIS versions. A new map developed between earlier versions completed a suite of mapping tools to enable existing datasets to be evaluated using contemporary estimates of severity. The second study attempted to relate common AIS summary scores to mortality risk or more objective measures of hospital-based morbidity, and determined that across AIS versions an adjustment of the summary score thresholds used to classify severely injured patients was necessary.

The second section of the thesis evaluated an alternative severity system based on the AIS codeset, the Functional Capacity Index (FCI). The FCI is attractive for trauma registries, as it was designed to predict 12-month outcomes using previously collected AIS codes. However, a literature review in this thesis revealed that it was unvalidated, and had not been applied to the common instance of multiple injuries. In isolation, the FCI offered improved predictions over AIS severity assessments for 12-month outcomes. However, both AIS-based and FCI-based scores added similarly - and often very little - to simple models which were being used to predict a range of functional outcomes. As such, the FCI is not fit for its designed purpose.

The consistent use of AIS coding over time is feasible. However, the prediction of different aspects of recovery after injury will require the development of specific scoring systems. These may be improved by addressing the subjectivity of the AIS and FCI severities on which such systems may be based.

Declaration

This thesis is an original work of my research and contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

Signature: [redacted]

Print Name: Cameron Palmer

Date: 1 July 2019

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This thesis is the result of eight years' work - or, at least, has taken eight years to complete. I and my life are both quite different compared with eight years ago, and there are many people who have shared this journey with me. The saying goes that it takes a village to raise a child - and apparently another to nurse an old PhD student through.

Firstly, a huge thanks to my supervisors, Professors Peter Cameron and Belinda Gabbe. Together they form a quite remarkable team, and their complementary approaches to planning, performing, writing and assessing research have ensured that I have been well-informed (and often well drilled) in both the 'big picture' and 'in depth' aspects of this work. It was their suggestion and encouragement which started me on this journey, their diligence and further encouragement which kept me on a straight path, and their (thoroughly undeserved) patience and encouragement which have enabled me to reach the end of this road. Peter and Belinda have been wonderful mentors, and I am by far the better researcher and writer for their advice.

Thanks must go to the former staff of the Queensland Trauma Registry who co-authored the first paper in this thesis - in particular to Jacelle Warren and Glen Russell.

Three of the papers in this thesis utilise data from the VSTR and VOTOR registries located within the Pre-hospital, Emergency and Trauma Research Unit at the Department of Epidemiology and Preventive Medicine. Particular thanks must go to Sue McLellan for her advice and work in retrieving data, but there have been many other colleagues and students within this department who have helped with anything from practical assistance to the right conversation at the right time, or just sharing the journey from their current or past experience. Beginning to name names is likely to lead to omissions - and some staff and students have moved on - but of note I would like to thank Ben Beck, Sandy Braaf, Jess Callaghan, Susie Cartledge, Christina Ekegren, Jess Hocking, Paul Jennings, Lara Kimmel, Alyse Lennox, Mimi Morgan, Tania Richter, Ann Sutherland and Krystle Wilson, as well as Kathryn Daly and Elizabeth Douglas.

For seventeen years I have managed the Trauma Registry at the Royal Children's Hospital, Melbourne. Within the Trauma Service I am fortunate to work alongside two of the most passionate trauma clinicians in existence - Helen Jowett and Warwick Teague. They have supported me to present the research from this thesis, although I am indebted to them not only because of this but also because of the examples set by their everyday service. I am also grateful for the friendship and support of past and present RCH staff Cvetanka Bogoeska, Rebecca Finlay, Sally-Anne Gavin and Marlene Jacobs.

I am part of a wider trauma community, and within this space there are many other dedicated clinicians and researchers who I am privileged to work alongside. Their collaboration, support, encouragement - and in one case competition - have greatly spurred me on in my research. Specifically, I would like to thank Grant Christey, Kate Curtis, Mel Franklyn, Rod McClure, Louise Niggemeyer, Cliff Pollard, Hideo Tohira and Daryl Wall.

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To my children, Finlay, Sienna, Phoebe, Juliet and Yvette - my life is made richer (and a lot more interesting) every day by having each of you in it. I love seeing you flourish and develop, and observing the future adults you are becoming. I am very proud of you all. And yes - now that Daddy is finished this PhD, I have time and will read, play, watch, build Lego and game with you.

To my wife Natalie - you make me a better person. Professionally, you are the first audience to all my work, and the most patient and long-suffering of those waiting for this day to arrive. Personally, you are my best friend, soulmate, my favourite person and the funniest woman I know. I love the way that our personalities complement each other, and our spirits build each other. You are the best thing about waking up each day. I love you.

And finally:

To our God and Father be glory for ever and ever. Amen.

Philippians 4:20

Publications and Presentations

This section lists only those publications which are presented in this thesis, and presentations of this work at various meetings. Other publications which are, or are not relevant to the research themes presented in this thesis are listed in Appendices One and Two, respectively.

Publications

2013

Palmer CS, Lang J, Russell G, Dallow N, Harvey K, Gabbe B, Cameron P. Mapping Abbreviated Injury Scale data from 1990 to 1998 versions: A stepping-stone in the contemporary evaluation of trauma. *Injury* 2013 Nov; 44(11):1437-1442. doi: 10.1016/j.injury.2012.08.033

2016

Palmer CS, Gabbe BJ, Cameron PA. Defining major trauma using the 2008 Abbreviated Injury Scale. *Injury* 2016 Jan; 47(1):109-115. doi: 10.1016/j.injury.2015.07.003

2017

Palmer CS, Cameron PA, Gabbe BJ. A review of the revised Functional Capacity Index as a predictor of 12 month outcomes following injury. Injury 2017 Mar; 48(3):591-598. doi: 10.1016/j.injury.2017.01.006

Palmer CS, Gabbe BJ, Cameron PA. Revised Functional Capacity Index as a predictor of outcome following injury. Br J Surg 2017 Dec; 104(13):1874-1883. doi: 10.1002/bjs.10638

2019

Palmer CS, Cameron PA, Gabbe BJ. Comparison of revised Functional Capacity Index scores with Abbreviated Injury Scale 2008 scores in predicting 12-month severe trauma outcomes. Inj Prev doi: 10.1136/injuryprev-2018-043085.

PRESENTATIONS

2011

Cameron Palmer. The Functional Capacity Index: Development, validation and future. Meeting of Technical Co-Operation Program - Action Group for the Mitigation of Battlefield Trauma, Australian Department of Defence Science Training Organisation, Melbourne, October 2011. Invited presentation.

2015

Cameron Palmer, Belinda Gabbe & Peter Cameron. Outcome prediction following severe injury: the Functional Capacity Index. Australasian Trauma Society 19th Annual Scientific Meeting, Gold Coast, October 2015. Oral presentation.

2016

Cameron Palmer, Belinda Gabbe & Peter Cameron. Outcome prediction following severe injury: the Functional Capacity Index. Third International Congress or the World Coalition for Trauma Care, New Delhi, August 2016. Oral presentation.

2018

Cameron Palmer, Peter Cameron & Belinda Gabbe. FCI and AIS2008 scoring for predicting 12-month severe trauma outcomes. Australasian Trauma Society 22nd Annual Scientific Meeting, Perth, October 2018. Oral presentation.

Declaration for Thesis Including Published Works

I hereby declare that this thesis contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

This thesis includes five original papers published in peer-reviewed journals. The core theme of the thesis is the assessment of injury severity, and how such assessments have changed over time - both in terms of the tools used to assess injury severity, and the outcomes which these tools are in turn used to predict. The ideas, development and writing up of all the papers in the thesis were the principal responsibility of myself, the student, working within the Department of Epidemiology and Preventive Medicine under the supervision of Professors Peter Cameron and Belinda Gabbe.

The inclusion of co-authors reflects the fact that the work came from active collaboration between researchers, and acknowledges input into team-based research. In the case of Chapters Two, Three, Four, Five and Six my contribution to the work is summarised overleaf.

Thesis chapter	Publication title	Status	Nature and % of student contribution	Co-authors and nature of contributions	Co-authors Monash students?
Two	Mapping Abbreviated Injury Scale data from 1990 to 1998 versions: A stepping-stone in the contemporary evaluation of trauma	Published	**60%** - Study conception and design; map development; direction of statistical analysis; development of tables; manuscript drafting and revision	Jacelle Lang - Co-performed map development; assisted with design, statistical analysis and manuscript revision	No
				Glen Russell - Assisted with design, statistical analysis and manuscript revision	No
				Natalie Dallow - Assisted with design and manuscript revision	No
				Kathy Harvey - Assisted with design and manuscript revision	No
				Belinda Gabbe - Assisted with design and manuscript revision	No
				Peter Cameron - Assisted with design and manuscript revision	No
Three	Defining major trauma using the 2008 Abbreviated Injury Scale	Published	**80 %** - Study conception and design; statistical analysis; development of tables and figures; manuscript drafting and revision	Belinda Gabbe - Assisted with manuscript revision	No
				Peter Cameron - Assisted with manuscript revision	No
Four	A review of the revised Functional Capacity Index as a predictor of 12 month outcomes following injury	Published	**80%** - Study conception and design; literature search and paper retrieval; development of tables and figures; manuscript drafting and revision	Peter Cameron - Study conception and manuscript revision	No
				Belinda Gabbe - Study conception and manuscript revision	No
Five	Revised Functional Capacity Index as a predictor of outcome following injury	Published	**70%** - Study conception and design; statistical testing; development of tables and figures; manuscript drafting and revision	Belinda Gabbe - Conception and design of study, and manuscript revision	No
				Peter Cameron - Conception and design of study, and manuscript revision	No
Six	Comparison of revised Functional Capacity Index scores with Abbreviated Injury Scale 2008 scores in predicting 12-month severe trauma outcomes	Published	**70%** - Study conception and design; statistical testing; development of tables and figures; manuscript drafting and revision	Belinda Gabbe - Conception and design of study, and manuscript revision	No
				Peter Cameron - Conception and design of study, and manuscript revision	No

I have not renumbered sections of published papers in order to generate a consistent presentation within the thesis.

Student: **Cameron Palmer**

Student signature: [redacted] **Date: 1 July 2019**

I hereby certify that the above declaration correctly reflects the nature and extent of the student's and co-authors' contributions to this work. In instances where I am not the responsible author I have consulted with the responsible author to agree on the respective contributions of the authors.

Main Supervisor: **Peter Cameron**

Main Supervisor signature: [redacted] **Date: 1 July 2019**

List of Abbreviations

AIS	Abbreviated Injury Scale
AAAM	Association for the Advancement of Automotive Medicine (previously, The American Association for Automotive Medicine)
CRIS	Comprehensive Research Injury Scale
CT	Computed Tomography
FCI	Functional Capacity Index
GOS-E	Glasgow Outcome Scale (Extended)
ICD	(World Health Organization) International Classification of Disease
IIS	Injury Impairment Scale
ISS	Injury Severity Score
JAMA	Journal of the American Medical Association
MAIS	Maximum Abbreviated Injury Scale
MRI	Magnetic Resonance Imaging
MRR	Mortality Risk Ratio
NISS	New Injury Severity Score
QTR	Queensland Trauma Registry
SRR	Survival Risk Ratio
VOTOR	Victorian Orthopaedic Trauma Outcomes Registry
VSTR	Victorian State Trauma Registry

"If you always do what you've always done,
you'll always get what you've always got."

Anonymous, often attributed to Henry Ford -
- not specifically in the context of injury severity scoring

Chapter One
Introduction

1.1 Background

1.1.1 Trauma - A Public Health Problem

Traumatic injury (hereafter called trauma) is a significant public health issue, estimated to cause more than 10% of the global disease burden.[1] It remains a leading cause of both death and disability in high-, middle- and low-income countries - particularly below 45 years of age - and accounts for a substantial component of both hospital and societal costs of disease.[2-7]

Although definitions of trauma vary, all definitions involve the concept of energy transfer (including deprivation, as in drowning or asphyxia). As such, workable definitions are:

> *"damage to the body produced by energy exchanges that have relatively sudden discernible effects"* [8]
>
> or
>
> *"the anatomic lesion resulting from a transfer of energy (e.g., mechanical, chemical, thermal) rather than a complication or immediate sequelae."* [9]

Trauma, therefore:

› occurs suddenly;

› can result from diverse external causes; and

› may affect any part of the body.

As a result, the effects of trauma can range from inconsequential to devastating. Non-fatally injured patients may be at risk of socioeconomic sequelae such as mental health issues,[10] reduced quality of life [11] and economic hardship.[12]

1.1.2 Classifying Trauma

Assessments of the 'severity' of trauma - in terms of both immediate and longer-term direct and indirect effects - are dependent on the outcome measure being used.[13-15] For example, a severe abdominal injury carries an inherent risk of death, but survivors of these events are likely to function well. Severe trauma to the eye, the hand or lower extremity is unlikely to be fatal, but will cause ongoing functional loss. Still other types of trauma, such as to the brain or cervical spinal cord, carry inherent risks for both mortality and functional loss amongst survivors. Many of these so-called 'dimensions' of severity exist; an (incomplete) listing of these includes:[16,17]

› threat to life (mortality risk - expected or actual);
› the amount of energy dissipated/absorbed;
› tissue damage sustained;
› the need for hospitalisation;
› the need for intensive care;
› the length of hospital stay;
› treatment cost;
› treatment complexity;
› the presence, duration and extent of disability;
› the degree of permanent impairment; and
› the loss of quality of life.

As a result, satisfactorily classifying disparate types of trauma to provide a global estimate of 'severity' (either for an individual patient, or to describe an injured population) is often difficult, and requires either compromise or a multifaceted approach.

1.1.3 The Abbreviated Injury Scale

The Abbreviated Injury Scale (AIS)[13,17-26] is a classification system for coding the type and severity of injuries. The AIS was first developed in 1968 and 1969 as a joint effort between American societies of engineers, physicians and crash researchers.[13,18,20,22,27,28] Initially based on the results of studies into light plane crashes in the 1940s and 1950s,[28-30] the AIS was developed to classify and study the results of automotive (occupant) crashes.[13,18] However, following its publication in JAMA in 1971,[18] the AIS became widely adopted [27,31] and was soon applied to trauma resulting from other mechanisms of injury.[32,33] The Association for the Advancement of Automotive Medicine (AAAM - until 1988,[34] the American Association for Automotive Medicine) was represented at the initial development of the AIS, and since 1973 has been responsible for co-ordinating modifications to, and producing the AIS.[28]

The AAAM defines the AIS thus:

> *"The AIS is an anatomically-based, consensus-derived, global severity scoring system that classifies each injury by body region according to its relative importance on a 6-point ordinal scale."* [16,17]

As such, the AIS provides a method of coding the epidemiology and relative severity of injuries sustained, both by an individual and within a population, in a standardised format. Unlike the globally-used World Health Organization's International Classification of Disease (ICD) coding, AIS nomenclature is both disease-specific and explicitly comparative.[35] The AIS is consequently attractive to clinicians, researchers and policymakers involved in trauma care. All of these groups have been represented on the successive committees which have developed and refined the AIS code structure, and assigned severity levels to those codes.[17]

The AIS has expanded through several version changes over the past 50 years (Table 1.1). Successive versions have enlarged the AIS codeset to provide for increased diagnostic specificity, provide clarification for coding accuracy, incorporate different types of trauma (such as penetrating or drowning injury), and to maintain consistency with terminology and clinical classifications used by physicians. Some AIS versions (such as the currently-used 2008 AIS update)[17] have only contained incremental modifications; others (such as the 2005 version [26] which preceded it) differed substantially from earlier versions. The 2005 and 2008 AIS also contain mapping tools to facilitate comparison between AIS versions, and migration of AIS data initially coded using earlier AIS versions.

The AIS is the de facto global standard for coding injuries in trauma registries worldwide, with most registries using the 2008 AIS.[36]

Table 1.1 Summary of AIS versions

The relative sizes of the AIS codeset in each version are shown, along with a summary of successive additions, expansions and revisions to the codeset.

Version year	Number of codes *	Key features / developments *
1969 [13]	59	Description of types of injury occurring at each AIS severity level
1971 [18]	74	Clarification and expansion of injury descriptions
1974 [19]	Unknown	Expansion of codeset [28]
1975 [20]	391	Removal of multiple fatal injury levels and introduction of 'unknown' severity Description of Overall AIS and Injury Severity Score (ISS) [31,37] summary scores
1976 [21]	252 [38]	Use of coding dictionary, including grouping of injuries into body regions
1980 [22]	462	Addition of instructions for ISS calculation Revision of rationale for brain injury coding
1985 [23]	1,237	Addition of codes for penetrating injury coding Use of five-digit injury codes for localisation, type and extent of injuries Revision of terminology for thoracic, abdominal and vascular injuries
1990 [24]	1,312	Addition of coding guidelines Expansion of brain and intracranial injury codes Addition of paediatric-specific codes for some injuries Revision of penetrating codes Use of six-digit injury codes incorporating type of structure injured
1998 [25]	1,341	Revision of coding guidelines Revision of paediatric-specific codes Inclusion of Organ Injury Scale codes for thoracic and abdominal injuries
2005 [26]	1,984	Addition of codes for blast and 'non-mechanical' injuries Inclusion of Orthopaedic Trauma Association's Fracture Classification system Addition of clarification graphics Expansion of terminology for facial fractures and ocular injuries Expansion of intracranial injury coding Addition of (incomplete) mapping to and from 1998 AIS version [39]
2008 [17]	1,999	Standardisation of AIS 2005 codeset variations [40] Inclusion of Functional Capacity Index

* - Comments made in these columns are from the relevant version of the AIS, except where noted.

1.1.4 AIS Summary Scores

Many patients who are severely injured sustain multiple injuries. Early users of the AIS recognised the need for summary scores which could describe the overall severity of a patient's injuries.[19,31,37] Since then, several scoring methods based on AIS codes have been developed.[19,22,31,37,41-53] These scores use a range of mathematical and transformative approaches using one, some or all of the injuries coded for a patient. Many of these scores group injuries according to arbitrary body regions, such as 'head' or 'abdomen'. Most of these measures have been little-used, and one - the Overall AIS - was specifically discouraged in the 1980 AIS due to its subjectivity (after being recommended by the 1976 AIS).[22] Apart from one recent score which continues to be evaluated,[49,54,55] only three AIS summary scores are currently in widespread use - the Injury Severity Score (ISS),[31,37] The New Injury Severity Score (NISS)[46] and the Maximum AIS (MAIS).[22]

Developed in 1974, the ISS is the oldest summary score. Following its publication it was rapidly adopted by AIS users,[19,32,33,41,56-59] and remains the most commonly used injury summary score in trauma registries [36] and trauma research [60] worldwide. The ISS is calculated as the sum of the squares of the maximum AIS levels in the three most severely injured ISS regions; six arbitrary body regions are used. The ubiquity of the ISS has led it to being regarded by some as the 'gold standard' for describing a patient's overall injury severity.[61-63] However, many mathematical, administrative and clinical limitations of the ISS have been identified,[14,59,62,64-77] and other AIS-based tools have been found to outperform the ISS in predicting mortality.[46,47,78-81] Despite this:

> *"The ISS has persisted because of familiarity and the simplicity of calculation."* [75]

The ISS is frequently used to identify subgroups of interest in registries and research, or to define severely injured populations. The most commonly used threshold for this purpose is an ISS>15, which is often used to denote 'major trauma'.[82-84] The ISS is also commonly used for mortality adjustment, either in isolation [36] or as part of a larger composite score.[82,85-87]

The NISS was developed specifically to improve upon the performance of the ISS.[46] The NISS is simpler to calculate, as the three squared AIS levels used are from the three most severe injuries overall (i.e., independent of body region). The NISS has outperformed the ISS in its ability to predict mortality and hospital resource utilisation in some studies,[62,78,80] and has replaced the ISS as the determinant of severe injury in some settings.[88-90] However, the NISS remains less widely used than ISS.[60,90]

The MAIS score is even simpler to use than the ISS and NISS, as it corresponds to the single most severe AIS level used in coding a patient's injuries. The MAIS is used to identify patients who have sustained serious injury, often for inclusion within a research or registry cohort.[91,92] The MAIS within a single body region (such as the head) may be used for a similar purpose, or within composite mortality prediction scores.[86]

The AIS or ISS have been used as components of several mortality-specific prediction tools and models.[47,82,85,86,93-98] Such tools have been used to provide mortality likelihood estimates adjusted for injury mechanism, physiology and age in addition to injury severity.[99] These estimates can be used to risk-adjust hospital or jurisdictional performance based on anticipated and observed mortality, and hence permit more sophisticated performance comparison ('benchmarking') between trauma populations.[69] However, as these are not wholly focused on the AIS they will not be discussed further.

1.1.5 Trauma Systems and the Use of AIS Scores

Time-critical interventions can affect the outcome of severe trauma events.[100] Effective societal organisation and prompt, comprehensive medical care can reduce trauma-related mortality, improve outcomes and decrease the cost ('burden') of trauma to society.[101-103]

More than fifty years ago, the United States' National Research Council published a report, *Accidental Death and Disability: The Neglected Disease of Modern Society.*[104] This report highlighted strategies known or believed to improve the incidence, severity, management and outcomes from trauma. Some of the report's recommendations, such as public first aid training, the development of safety standards across private and public sectors and the adoption of a universal, simple emergency services telephone number are now commonplace in many countries. Several recommendations related to the implementation of inclusive trauma systems within geographic areas (whether regionally or nationally). These included:

› appropriate training and equipping of, and the integration of ambulance services with hospitals and relevant authorities such as traffic and health;

› categorisation and accreditation of hospitals by resource and skill level;

› organisation, siting and funding of trauma hospitals of different levels by region or country;

› establishment of trauma registries at hospital and national levels to provide evidence for injury prevention, care assessment and outcomes monitoring;

› an evidence-based approach to quantifying disability, with an emphasis on return to productive work and early measures for rehabilitation;

› use of case review, both by hospitals and as part of coronial processes, to provide feedback and drive improvements in care; and

› provision of adequate funding for trauma research, commensurate with the magnitude of the burden of injury.

These concepts have been implemented, to greater or lesser extents, as systems of trauma care across many regions in the past fifty years. Trauma systems have since been demonstrated to reduce both mortality [105-107] and morbidity [103] within jurisdictions, as well as when risk-adjusted comparisons are made with jurisdictions without such systems in place.[97]

The ISS, NISS and MAIS are used as fundamental components of many aspects of modern trauma systems as envisaged by the 1966 National Research Council Report.[104]

› ISS and MAIS thresholds are used as a goal of, and to assess the effectiveness of field triage and inter-hospital transfer criteria;[108-113]

› ISS thresholds are used as a component of classification and accreditation of major trauma hospitals;[83,84]

› trauma systems are funded based on expected or actual numbers of ISS-defined major trauma patients;[83,108,114]

› ISS thresholds are used to identify patients for audit;[84] and

› AIS, MAIS, ISS and NISS are used as inclusion criteria or mandated fields for large data collections, to benchmark and drive further system change.[88,91,115,116]

Other composite measures and models have included the AIS in some form to assess the quality of care (based on expected mortality given trauma severity and population demographics) within trauma systems, and benchmark outcomes within or across trauma systems or over time.[117-121]

Trauma systems continue to reflect contemporary thinking regarding the assessment, treatment and outcomes of injured patients within a population. Through derived summary scores, the AIS directly underpins many aspects of the function and evaluation of these trauma systems. It follows, therefore, that the ability of trauma systems to consistently assess performance either between regions, or over time is dependent - at least in part - on the stability and reproducibility of AIS coding.[35] Put another way, any changes to how the AIS describes anatomical injury pose a potential threat to the consistent monitoring - and performance - of trauma systems.

1.1.6 Accounting for AIS Change

There are two significant threats to the ongoing utility of the AIS over time. The first of these is the effect of AIS version change on assessed severity.[39,122-133] In order to maintain currency with contemporary evaluation and management of injuries, the AAAM review the assigned severity of injury codes within the AIS prior to the release of each version.[16,17] Consequently, the severities of AIS codes representing similar injuries across different AIS versions may differ. Although such modifications are intuitively appropriate, they have been found to result in substantial changes to derived MAIS,[127] ISS [39,122-126,128,129,131-133] and NISS [129] even within the same population.

The issue is exemplified in Table 1.2, which illustrates how AIS coding for cerebral epidural haematomas (bleeding between the skull and the membrane surrounding the brain) has changed over time. At the time the AIS was initially developed, such injuries were generally regarded as life-threatening as the limited use of imaging meant that they were often diagnosed during urgent surgical intervention or post-mortem examination. Due to improvements in both the diagnosis of these injuries - as occurred with the introduction of computed tomography (CT) and later magnetic resonance imaging (MRI) scans in the 1970s and 1980s - and their timely evaluation and management due to the implementation of trauma systems, epidural haematomas may now be detected at sizes which are clinically less relevant and only of moderate severity. Similar changes to AIS codes over time can substantially affect the assessment of injury severity within populations.[39] The result is the loss of comparability over time within a single dataset, or the ability to risk-adjust for injury in benchmarking comparisons using registries which employ different AIS versions.

Table 1.2 Illustration of AIS severity change over time

Code(s) used to describe cerebral epidural haemorrhage within selected AIS versions are provided, along with the assessed AIS severity level. Note that some successive versions used the same code(s) to describe these injuries.

Summary score	AIS code(s)	Description of specific injury code	AIS severity
1969 [13] 1971 [18] 1974 [19]	Head & Neck, Level 5	Intracranial haemorrhage	5
1980 [22]	Head, Level 4	Epidural haematoma, ≤100cc or unspecified	4
	Head, Level 5	Epidural haematoma, >100cc	5
1985 [23]	20505.4	Cerebrum » Hematoma » Epidural, not further specified	4
	20506.4	Cerebrum » Hematoma » Epidural, ≤100cc	4
	20507.5	Cerebrum » Hematoma » Epidural, >100cc	5
1990 [24] 1998 [25]	140630.4	Cerebrum » Hematoma » Epidural, not further specified	4
	140632.4	Cerebrum » Hematoma » Epidural, small (≤50cc / ≤1cm thick)	4
	140634.5	Cerebrum » Hematoma » Epidural, small - bilateral	5
	140636.5	Cerebrum » Hematoma » Epidural, large (>50cc / >1cm thick)	5
2005 [26] 2008 [17]	140630.3	Cerebrum » Hematoma » Epidural, not further specified	3
	140631.2	Cerebrum » Hematoma » Epidural, tiny (<0.6cm thick)	2
	140632.4	Cerebrum » Hematoma » Epidural, small (≤50cc / 0.6-1cm thick)	4
	140634.5	Cerebrum » Hematoma » Epidural, small - bilateral	5
	140636.5	Cerebrum » Hematoma » Epidural, large (>50cc / >1cm thick)	5

One solution to this is the development of maps between AIS versions.[26,129] Mapping involves the development of conversion tables which, for a given AIS code in a given AIS version, specify the equivalent AIS code (or codes) in a different version.[129] These can produce AIS datasets which are close estimates of the datasets which would have been produced if an alternate AIS version had been used.[129] Several authors have developed tools to map between the 1998 and 2005 or 2008 AIS versions.[17,26,40,131,134,135] By double-coding patients using two AIS versions, the severity scores derived from mapped datasets have been shown to be comparable with directly coded ISS and NISS,[131,134,135] although some differences between the performances of mapping tools have been demonstrated.[136] However, not all AIS versions in widespread use have mapping tools available.

Even if accurate mapping can be achieved, the uses to which AIS summary scores are put require periodic re-assessment. In particular, using ISS, NISS or MAIS thresholds for defining injured subgroups across different AIS versions will result in the identification of different patient populations.[39,128,129] As a result, the adoption of contemporary AIS versions as they are developed - to maintain currency in severity assessment - necessitates re-evaluation of how AIS summary scores are used.[35,39,132,137]

1.1.7 Defining Injury Severity Using the AIS

A second threat to the ongoing utility of the AIS lies in the definition of 'severity' as assigned to AIS codes. The initial versions of the AIS were explicitly linked to five measures of severity - threat-to-life, energy dissipation, incidence, treatment period and permanent impairment.[13,18,27,138] A related Comprehensive Research Injury Scale (CRIS) was developed at the same time as the AIS;[27,138] this contained severity indices specific to each of these dimensions across an expanded set of 283 injury codes. The term 'abbreviated' in the name of the AIS hence applies to the use of only one severity level to describe an injury,[22,28] rather than the size of the AIS codeset. However, the AAAM presently use a somewhat circular definition for the level assigned (bold text added):

> *"The AIS single digit* ***severity*** *number indicates the relative* ***severity*** *of injury in an average patient who sustains the coded injury as his only injury."* [9]

During the initial development of the AIS, severity was primarily determined by two dimensions: threat-to-life, which was of primary interest to the physicians involved with the AIS and CRIS, and energy dissipation, which was of primary interest to crash engineers.[13,27] However, subsequent analysis demonstrated that mortality predominated in AIS severity assessments,[38] and for more recent versions this has since been stated explicitly by the AAAM and affiliated researchers.[15,16,139] In this context, it is worth noting both early (1972) and more recent (2006) opinions expressed by developers of the AIS:

> *"The major limitation of the Abbreviated Injury Scale is that the various criteria used in rating injuries cannot readily be identified and separated... these criteria are lumped into a rating, and the weights given each vary in the minds of various researchers."* [138]

> *"AIS is a threat to life scale, but it is not only a threat to life scale and since it was not designed only to correlate to mortality, it is not unexpected that there is not a linear or perfect correction of AIS value and mortality."* [16]

It follows that inconsistencies in the definition of severity across the AIS codeset - not to mention across AIS versions - will cause variations in the performance of AIS-derived tools which attempt to predict a particular outcome. Indeed, the intentional use of a combination of severity criteria hinders the AIS - or its derived scores - from providing optimal estimates for any given outcome. It is consequently unsurprising that the developers of the ISS stated that its predictive utility (for any outcome) would be questionable at individual case level.[57]

In high-income countries where trauma systems are already established, substantial further improvements in trauma mortality rates are less likely.[101,140] As a result, measures of morbidity amongst survivors of severe trauma, such as quantifying the overall burden of injury in a population or measuring the quality of survival, are necessary to identify improvements in trauma system performance.[15,35,101,102,140-145] It has been demonstrated that the routine collection of such outcomes is feasibile.[143,146,147] However, most trauma systems do not routinely measure outcomes beyond mortality or hospital-based severity measures.[101,144,148]

Permanent impairment was one of the severity dimensions considered in AIS severity assessments. However, it was used rarely and inconsistently across the AIS codes;[27] later AIS versions explicitly stated that disability and impairment were not measured by the AIS.[24,25] As a result, although associations have been found between assessed disability and AIS or ISS, levels of agreement were low.[56,149] The permanent impairment scale of the CRIS [27,138] has not been used in subsequent research.

Since the 1970s, two further attempts have been made to create alternate severity levels to the AIS structure, based on predicted levels of impairment (or function) in surviving injured patients. The first of these, the Injury Impairment Scale (IIS)[150-153] and a related Injury Disability Scale,[153] were developed to parallel the 1990 AIS revision. However, the IIS performed poorly on initial validation studies,[154-156] and has now lost currency due to AIS version changes.

A second attempt to utilise the coding structure of the AIS to predict non-fatal outcomes was the predictive Functional Capacity Index (FCI).[15,157,158] Developed at the same time as the IIS, the FCI assigned alternate severities to codes in the 1990 AIS revision. These severities were thought to reflect the expected residual functional limitation resulting from a given injury twelve months after a trauma event.[15] The FCI only demonstrated modest agreement with measured functional outcomes.[159-161] In spite of this, the FCI was later revised and a truncated version included within the 2008 AIS dictionary.[17,162] This scale is consequently attractive as a means to estimate morbidity burden in trauma populations by using previously- or concurrently-coded AIS data.[143] However, the actual predictive utility of the revised FCI remains unknown.

1.1.8 Summary

The Abbreviated Injury Scale is an integral component of the function and monitoring of modern trauma systems. However, the uses to which the AIS and its derived scores are put require confidence in the consistency of the underlying AIS codeset. This has changed substantially over time, resulting in uncertainty where AIS version differences exist within or between datasets, and where thresholds are used over time with AIS-based summary scores to identify severely-injured patients or patient cohorts. It is therefore imperative that existing methods for evaluating injury severity remain current. This can be achieved by assessing and adjusting for the effects of AIS version change on how the severity of an injured population is described. In addition, AIS summary scores such as the ISS should be used in ways which are relevant to the outcomes of interest, and which consistently measure those outcomes in spite of AIS version change.

At the same time, the routine evaluation of outcomes other than mortality or hospital-based severity measures has for decades been recognised as a desirable goal. However, most trauma systems do not measure functional outcome or quality of life. An AIS-based severity measure which can successfully predict ongoing population morbidity would be attractive. However, the predictive FCI - the most current tool claiming to fulfil these criteria - has not been sufficiently evaluated.

1.2 Research Aims

The title of this thesis is ***The contemporary evaluation of trauma outcomes***. The overall aim of this thesis is to evaluate and develop validated tools for the use and interpretation of injury data coded using the most current AIS version, and to identify and develop principles for severity assessment which are likely to remain valid for future revisions of the AIS.

This overall aim has been broken into two more specific aims which serve as different interpretations of the thesis title, and guide the two research aspects which this thesis examines.

Aim I - To develop and evaluate methods for maintaining comparability of trauma severity assessments between AIS versions over time

Aim II - To review and evaluate AIS-based methods for predicting functional outcomes following severe trauma

1.3 Thesis Outline

1.3.1 Overview

This thesis comprises seven chapters, and forms a PhD by publication containing five separate papers with a single research aim, grouped under two more specific aims. An outline of the chapters in this thesis, together with the relevant research aims for each component paper is presented in Table 1.3.

The current chapter has provided an overview of the importance of the AIS to trauma systems, which are regarded as the foundation of successful management of trauma as a public health issue. The AIS-related research which comprises this thesis acts as the continuation of, and builds upon a research theme which commenced prior to this thesis. The program of research presented in this thesis commenced in June 2011. Prior to, and contemporaneous with this research, a further seven publications published between 2010 and 2019 - six conceived and written by the candidate, and a sixth co-authored by the candidate - are relevant to this theme, and are summarised in Appendix One.

A common term used in this thesis is 'contemporary' - literally, 'with the (present) time' - and provides a template for research evaluating and maintaining the relevancy of the AIS to assessments of trauma severity. The two specific aims - interpretations of the thesis title - will be addressed as two aspects of the same overall aim.

Table 1.3 Outline of thesis by research goal and chapter

Chapter	Contents	Research Aims
Chapter One	Introduction	Research aims of previous AIS-related research are presented in Appendix One.
Aim I - The evaluation of trauma using the contemporary AIS		
Chapter Two	Paper: *Mapping Abbreviated Injury Scale data from 1990 to 1998 versions: A stepping-stone in the contemporary evaluation of trauma*	Primary aims: *1) To develop a map capable of transforming an AIS90-coded dataset into an AIS98-based (mapped) dataset.* *2) To describe and assess differences in ISS between an AIS90-coded dataset, and the AIS98-mapped dataset generated using this map.*
Chapter Three	Paper: *Defining major trauma using the 2008 Abbreviated Injury Scale*	Primary aim: *1) To identify ISS and NISS thresholds, based on AIS08-coding, which perform similarly to the earlier ISS >15 threshold for AIS98-coded data in predicting mortality following trauma.* Secondary aims: *1) To evaluate the variability in mortality across a range of possible ISS and NISS values.* *2) To assess ISS and NISS thresholds in measuring in-hospital service requirements.*
Aim II - Using the AIS to evaluate contemporary (non-fatal) trauma outcomes		
Chapter Four	Paper: *A review of the revised Functional Capacity Index as a predictor of 12 month outcomes following injury*	Primary aims: *1) To review the construction and validation of the predictive FCI.* *2) To review the modifications made to the 'original' FCI which produced the current 'revised' FCI and its truncated version used in the 2008 AIS Dictionary.* *3) To review the extent to which this revised tool has been validated and used.*

Chapter	Contents	Research Aims
Chapter Five	Paper: *Revised Functional Capacity Index as a predictor of outcome following injury*	Primary aims: *1) To assess whether the FCI contained within the AIS08 dictionary was capable of predicting 12-month functional outcomes across a major trauma population.* *2) To assess whether FCI predictions were superior to those offered by AIS08 severities.* Secondary aim: *1) To assess whether the arbitrary assumptions, particularly that relating to age, inherent in the design of the FCI were necessary for population homogeneity in a group of otherwise healthy patients with isolated injury.*
Chapter Six	Paper: *Comparison of revised Functional Capacity Index performance with Abbreviated Injury Scale 2008 measures in predicting 12-month severe trauma outcomes*	Primary aim: *1) To determine the extent to which AIS-based and FCI-based scores are able to add to a simple predictive model of 12-month functional outcomes in a severely injured population.* Secondary aim: *1) To evaluate potential methods of using FCI scores in instances where patients have sustained multiple injuries.*
Chapter Seven	Discussion, Key findings and recommendations, and Concluding remarks	

1.3.2 Aim I - Maintaining Comparability Between AIS Versions

The AIS is regarded by its developers as itself being a "contemporary injury scale".[16] The first section of the thesis involves two considerations of how the AIS, ISS and NISS have been used to evaluate trauma to this point. Firstly, the development of a new map between AIS versions enables the comparison of data coded using different AIS versions over time or between jurisdictions. Secondly, exploring how ISS or NISS thresholds are used across AIS versions to classify patients at elevated risk of dying or requiring ICU or urgent surgery enables consistency in how severely injured patients are defined.

The development of a mapping tool is described in Chapter Two. This tool complements previously developed maps capable of migrating AIS-coded datasets between the 1998 and 2008 versions. By documenting the AIS codeset differences, and resultant ISS differences between the 1998 AIS and the similar, widely-adopted 1990 AIS (Table 1.1), a small 'stepping-stone' map was developed. This completed the development of tools which enabled the re-assessment of established registry datasets using the most contemporary AIS version.

Summary scores utilising AIS codes are commonly used to set a threshold to define a major trauma population for the purposes of trauma system evaluation and risk-adjustment. In the light of AIS codeset changes, the most widely-used ISS threshold is re-assessed in Chapter Three. The rationale which underpinned this threshold was re-applied to an AIS dataset which had been mapped between the 1998 and 2008 AIS versions. ISS and NISS thresholds which approximated the performance of the older cut-off were determined and then evaluated against their ability to predict mortality and hospital-based resource utilisation. This provided a useful 'stop-gap' solution when assessing trauma outcomes using these older measures.

1.3.3 Aim II - Predicting Functional Outcomes Following Trauma

Routine evaluation of trauma care and the impact of trauma systems have previously been focused on mortality. Despite this, regions with established trauma systems have identified that the collection of outcomes other than mortality - namely the function and quality of life resulting from trauma amongst surviving trauma patients - is preferable. This section of the thesis focuses on the

FCI as the companion scale to the AIS, and seeks to contemporise which trauma outcomes are evaluated. Firstly, the construction, properties, previous use and potential utility of the predictive FCI will be reviewed. Secondly, the ability of this tool to predict a range of functional and quality of life outcomes - over and above the assessed severities of the AIS, and in addition to other predictive factors - will be evaluated in two separate, but complementary studies.

An AIS-structured scale designed to predict functional outcomes following severe injury offers substantial potential. To this end, the purpose, development, validation and revision of the FCI are reviewed in Chapter Four. The level of validation of both the truncated FCI in the AIS dictionary and the larger version on which it was based were found to be poor. A number of directions for future validation of the FCI are identified, to explore the potential for routine evaluation of contemporary (non-fatal) outcomes using AIS-coded datasets.

Based on the need identified in the previous chapter, a preliminary validation of the FCI based on the population restrictions imposed by the FCI's developers is described in Chapter Five. Although these restrictions were demonstrated to be largely unnecessary, the comparatively weak association between the FCI and assessed 12-month outcomes in a major trauma population raises questions about the overall utility of the FCI.

Because the performance of FCI in the preceding chapter was equivocal, the final study evaluates the ability of the FCI to add to the ability of a simple model to predict a range of functional and health-related quality of life measures. This is reported in Chapter Six. While the FCI significantly improved model performance, it was functionally no better than other AIS-based tools.

1.3.4 Summary

Following on from the findings of the preceding chapters, the limitations of existing AIS-based tools in the contemporary evaluation of trauma outcomes are discussed in Chapter Seven. At the same time, the release of another new AIS version requires further assessment of the applicability of AIS-coded data to outcomes assessment. Recommendations for future methods of using and evaluating the AIS are proposed and discussed. The conclusions of the thesis draw lessons not only from the new findings of this thesis, but also from the wealth of previous literature using and evaluating the AIS over several decades.

Chapter Two
Completing AIS Mapping Tools

2.1 Overview of Chapter

The utility of mapping as a technique for enabling the comparison of datasets coded using different AIS versions was highlighted in Chapter One. To this point, AIS mapping tools have only been developed between the 1998, 2005 and 2008 versions. However, the preceding 1990 AIS version was widely adopted. Large national datasets were developed based on the 1990 AIS,[163,164] and it was still in worldwide use as late as 2015.[36] The differences between the 1990 and subsequent AIS versions, and their effects on derived scores such as the ISS, have not been quantified. Consequently, these datasets cannot be used to benchmark performance against registries using newer AIS versions, or over time within a registry if the AIS version has been updated.

The paper presented in this chapter applies the principles developed in earlier mapping work to the setting of data coded using the 1990 AIS. The differences between the 1990 and subsequent 1998 AIS versions were known to be comparatively small. As such, generating and validating a small map comprising identified differences between these versions was recognised as a simpler option to facilitate the conversion of 1990 AIS datasets to the more contemporary 2008 AIS. The new map would function as a 'stepping stone' to link into the previously-developed 1998 AIS to 2008 AIS map.

The following paper, 'Mapping Abbreviated Injury Scale data from 1990 to 1998 versions: A stepping-stone in the contemporary evaluation of trauma' was accepted for publication by Injury in August 2012, and published in print in November 2013. It is currently available online via the following link:

https://www.injuryjournal.com/article/S0020-1383(12)00343-9/fulltext.

2.2 Published Paper

Mapping Abbreviated Injury Scale data from 1990 to 1998 versions: A stepping-stone in the contemporary evaluation of trauma

Declaration for Thesis Chapter Two

Palmer CS, Lang J, Russell G, Dallow N, Harvey K, Gabbe B, Cameron P. Mapping Abbreviated Injury Scale data from 1990 to 1998 versions: A stepping-stone in the contemporary evaluation of trauma. Injury 2013 Nov; 44(11):1437-1442. doi: 10.1016/j.injury.2012.08.033

In the case of Chapter Two, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Study conception and design; map development; direction of statistical analysis; development of tables; manuscript drafting and revision	60%

The following co-authors contributed to the work. There are no student co-authors.

Name	Nature of contribution
Jacelle Lang	Co-performed map development; assisted with design, statistical analysis and manuscript revision
Glen Russell	Assisted with design, statistical analysis and manuscript revision
Natalie Dallow	Assisted with design and manuscript revision
Kathy Harvey	Assisted with design and manuscript revision
Belinda Gabbe	Assisted with design and manuscript revision
Peter Cameron	Assisted with design and manuscript revision

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the candidate's and co-authors' contributions to this work.

Candidate's signature	[redacted]	Date: 1 July 2019
Main supervisor's signature	[redacted]	Date: 1 July 2019

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Mapping Abbreviated Injury Scale data from 1990 to 1998 versions: A stepping-stone in the contemporary evaluation of trauma

Cameron S. Palmer [a,b,*], Jacelle Lang [c], Glen Russell [c], Natalie Dallow [c], Kathy Harvey [c], Belinda Gabbe [b], Peter Cameron [b]

[a] Trauma Service, The Royal Children's Hospital Melbourne, Australia
[b] Department of Epidemiology and Preventive Medicine, Monash University, Melbourne, Australia
[c] Centre of National Research on Disability and Rehabilitation Medicine, The University of Queensland, Brisbane, Australia

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ABSTRACT

Introduction: Many trauma registries have used the 1990 revision of the Abbreviated Injury Scale (AIS; AIS90) to code injuries sustained by trauma patients. Due to changes made to the AIS codeset since its release, AIS90-coded data lacks currency in the assessment of injury severity. The ability to map between the 1998 revision of AIS (AIS98) and the current (2008) AIS version (AIS08) already exists. The development of a map for transforming AIS90-coded data into AIS98 would therefore enable contemporary injury severity estimates to be derived from AIS90-coded data.
Methods: Differences between the AIS90 and AIS98 codesets were identified, and AIS98 maps were generated for AIS90 codes which changed or were not present in AIS98. The effectiveness of this map in describing the severity of trauma using AIS90 and AIS98 was evaluated using a large state registry dataset, which coded injury data using AIS90 over several years. Changes in Injury Severity Scores (ISS) calculated using AIS90 and mapped AIS98 codesets were assessed using three distinct methods.
Results: Forty-nine codes (out of 1312) from the AIS90 codeset changed or were not present in AIS98. Twenty-four codes required the assignment of maps to AIS98 equivalents. AIS90-coded data from 78,075 trauma cases were used to evaluate the map. Agreement in calculated ISS between coded AIS90 data and mapped AIS98 data was very high (kappa = 0.971). The ISS changed in 1902 cases (2.4%), and the mean difference in ISS across all cases was 0.006 points. The number of cases classified as major trauma using AIS98 decreased by 0.8% compared with AIS90. A total of 3102 cases (4.0%) sustained at least one AIS90 injury which required mapping to AIS98.
Conclusions: This study identified the differences between the AIS90 and AIS98 codesets, and generated maps for the conversion process. In practice, the differences between AIS90- and AIS98-coded data were very small. As a result, AIS90-coded data can be mapped to the current AIS version (AIS08) via AIS98, with little apparent impact on the functional accuracy of the mapped dataset produced.

Introduction

The value of trauma registries is largely dependent on the utility of the data which they contain. The Abbreviated Injury Scale (AIS)[1–3] has served as the foundation of trauma registries worldwide for decades. The AIS allows meaningful comparison of injuries of different types and severity, and forms the basis of summary injury scores such as the Injury Severity Score (ISS)[4] and the Trauma and Injury Severity Score (TRISS).[5] Such scores can be used in benchmarking, outcome prediction and evaluation of the quality of care of trauma patients.[4,6]

Since the initial publication of the AIS, nine revisions and updates have incrementally expanded the type and detail of injuries which the AIS can describe. The assigned severity levels for many injuries have also changed over time, to reflect concurrent improvements in the diagnosis, treatment, and prognosis of these injuries. This may affect the monitoring of trends in injury severity over extended periods of time, or in benchmarking between systems using different AIS versions.

The 1990 revision of the AIS[1] was adopted by a large number of trauma registries. An updated codeset was released in 1998,[2] providing a number of revisions to the AIS90 codeset. Differences between AIS90 and AIS98 have been assessed by only one previous study.[7] Although differences between the AIS90 and AIS98

* Corresponding author at: Trauma Service, The Royal Children's Hospital Melbourne, Australia. Tel.: +61 3 9345 4806; fax: +61 3 9345 6668.
E-mail address: cameron.palmer@rch.org.au (C.S. Palmer).

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codesets were comparatively small, the ISS changed for 23% of patients in the sample.[7] In part, this was due to changes in ISS coding rules for external injuries, which were simplified in AIS98. However, it was not clear whether injuries to particular structures or body regions disproportionally contributed to ISS differences, as has been noted with other AIS version changes.[8–10] It was also unclear whether ISS changes between AIS90 and AIS98 would affect the number of patients classified as 'major trauma', which is commonly defined using an ISS greater than 15.[5]

The most current revision of the AIS is the 2008 update to the 2005 edition (AIS08).[3] The AIS08 dictionary contains a map to transform AIS98-coded injuries to the much larger and more complex AIS08. This map is incomplete,[11] although supplementary mapping tools capable of completing this process have since been developed.[12,13] As a result, if the comparatively small differences between AIS90 and AIS98 could be completely identified, and appropriate AIS98 equivalents identified for AIS90 codes, it would be possible to map AIS90-coded injury data to AIS08. In other words, the development of an AIS90 to AIS98 map would serve as a small 'stepping-stone' to allow transformation of AIS90-coded data to the current AIS08. Given the size and complexity of the AIS98 to AIS08 map, the 'stepping-stone' approach is felt to be preferable to the development of a direct AIS90 to AIS08 map, as the majority of the differences between AIS90 and AIS08 are likely to already be contained within the existing AIS98 to AIS08 mapping tools. However, there is currently no map for transforming AIS90-coded data to any more recent AIS version.

The aims of this study were to develop a map capable of transforming an AIS90-coded dataset into an AIS98-based (mapped) dataset, and to describe and assess differences in ISS between an AIS90-coded dataset, and the AIS98-mapped dataset generated using this map.

Materials and methods

Development of an AIS90 to AIS98 map

The differences between the AIS90 and AIS98 codesets were identified, through manual review of the AIS90 and AIS98 dictionaries. The AIS90 dictionary used was copyrighted in that year, while the AIS98 dictionary used was re-copyrighted in 2001. Comparisons were performed independently by two authors (CSP and JL). Following this, discussions were held between these authors to ensure that the list of identified differences was complete. Both authors had a statistical and epidemiological background, had completed a number of AIS scaling courses, and had both practical and research experience in using AIS data.

The AIS98 equivalents were assigned for each AIS90 code which changed or had been removed in AIS98, depending on the nature of the changes made to each code. The same authors who identified differences between the AIS90 and AIS98 codesets also assigned these equivalent codes, both independently and during subsequent discussion. As with a previous study where AIS maps were developed,[12] the selection of plausible AIS98 maps was governed by established AIS coding guidelines.[2]

Comparison between AIS90-coded and AIS98-mapped datasets

Established in 1998, the Queensland Trauma Registry (QTR) collected data on seriously injured people in the state of Queensland. Queensland contains a population of approximately 4.5 million people, living in the north-east of Australia. In 2003, 15 hospitals participated in the QTR, with one additional hospital commencing during the study period. These hospitals are estimated to account for more than 90% of seriously injured patients admitted to Queensland public hospitals.[14] Data were manually entered onto the registry by QTR employees based at each hospital. All coders had a background in either nursing or health information management, and were trained using AIS scaling courses.

With some exclusions, patient cases were included on the QTR if they were admitted to a participating hospital for 24 h or more for the acute treatment of injury, or died after ED presentation (regardless of length of admission), and were coded to an injury-related category in ICD-10-AM (the Australian modification of the International Statistical Classification of Diseases).[14]

All cases meeting QTR inclusion criteria between January 2003 and December 2008 were included in the current study. De-identified data were retrieved from the QTR for each case, including all AIS90 injury codes and descriptors along with the assigned ISS body region. The developed AIS90 to AIS98 map was applied to this dataset to generate AIS98 mapped codes for all AIS90 codes. The ISS was then calculated for all cases using both AIS90-coded and AIS98-mapped data.

Data analysis and statistical methods

For the development of the AIS90 to AIS98 map, the observed differences between AIS90 and AIS98, and features of the mapping tool developed as a result, were summarised.

Differences in ISS calculated from the AIS90-coded and AIS98-mapped datasets were assessed in two ways. Firstly, because of the ordinal, irregular nature of the ISS[2,15–17] a summary table was produced to illustrate the spread of agreement between AIS90- and AIS98-based ISS. This was evaluated using a kappa score, and comparison of the mean ISS difference between the datasets. A quadratic weighted kappa was also calculated, as this is equivalent to the intra-class correlation coefficient for ordinal data.[18] Secondly, the change in the number of cases classified as major trauma between AIS90 and AIS98 was assessed, using percentage changes and kappa scores.

A *p*-value of 0.05 was taken as indicative of statistical significance, and 95% confidence intervals (CI) were calculated for proportions and kappa values. Ethics approval for this study was given by the Queensland Health Department, The University of Queensland and Monash University.

Results

Evaluation of AIS90 and AIS98 codesets and map generation

Table 1 summarises the differences identified between the AIS90 and AIS98 codesets. There were 23 AIS90 codes that were not present in AIS98, and 52 new codes were added. The size of the codeset consequently increased from 1312 codes in AIS90 to 1341 codes in AIS98. The identified changes equated to 3.7% of the AIS90 codeset (49 of 1312 codes), and 5.8% of the AIS98 codeset (78 of 1341 codes). Where both the localising (pre-dot) and severity component of the AIS code remained unchanged between the two versions, in all but one instance it was judged that a given injury would have been assigned the same AIS code in both AIS90 and AIS98 had double-coding taken place.

The 49 AIS90 codes which changed or were not included in AIS98 fell into two categories – those requiring map assignment, and those which did not. Twenty-six codes had a simple change in localising or severity component between AIS90 and AIS98 (Table 1); 25 of these codes had unchanged injury descriptors, and did not require a map (listed in Table 2). The remaining code had a changed injury descriptor and required a map.

In total, 24 AIS90 codes required mapping to AIS98; these codes are listed in Table 3. In the majority of instances where an AIS90 code was not present in AIS98, the AIS90 code reflected anatomical or age-related specificity that was removed in AIS98. An AIS98

Table 1
Summary of changes to AIS codeset made between AIS90 and AIS98.

	Code count	Relevant table
Total codes in AIS90	**1312**	
Codes and descriptors unchanged	**1263**	
Codes changed between AIS90 and AIS98	**26**	
Changed localising component only; descriptor and severity component unchanged in AIS98	13	Table 2
Changed severity component only; descriptor and localising component unchanged in AIS98	12	Table 2
Increased severity in AIS98	1	
Decreased severity in AIS98	11	
Changed injury descriptor – localising and severity component unchanged in AIS98 (*map required*)	1	Table 3
AIS90 codes removed; not present in the AIS98 codeset	**23**	Table 3
Specificity provided in AIS90 removed in AIS98 (*map required*)	15	
No equivalent code exists in AIS98 (*map required*)	5	
Other codes (*map required*)	3	
New codes added to AIS98	**52**	
Total codes in AIS98	**1341**	

code reflecting the lower specificity was therefore assigned as a map for these AIS90 codes. The AIS90 codeset also contained five codes relating to accidental hypothermia not associated with treatment. Although AIS98 did not contain hypothermia-related codes, they were re-introduced in AIS08 (Table 3).

There were four AIS90 codes for which AIS98 map selection was not immediately evident due to changes in injury descriptors - those for traumatic brain injury (not further specified – NFS), skull fracture (NFS) and two levels of duodenal perforation (Table 3). AIS98 equivalents for these codes were selected based on AIS98 coding rules.

Ten of the AIS90 codes listed in Table 3 changed in injury severity when mapped to AIS98. Five codes relating to femur fractures had a higher severity when mapped to AIS98, and the remaining five codes had a lower severity. When combined with the 12 codes that changed severity in Table 2, a total of 22 codes changed in severity between AIS90 and AIS98. Five codes decreased in severity by two AIS levels, 11 decreased by one AIS level and six increased by one AIS level.

Evaluation of AIS90 to AIS98 mapping

Over the six year sample period, 78,110 cases with recorded AIS90 codes were included on the QTR. A total of 195,628 AIS90 codes were assigned to these cases. Eight cases were only assigned AIS90 codes of non-specific (level 9) severity (nine codes in total) which precluded the calculation of ISS, and 27 cases sustained hypothermia injuries which could not be mapped to AIS98. The remaining 195,592 injuries sustained by 78,075 cases were mapped to AIS98.

Differences in ISS between AIS90 and AIS98

A total of 3102 cases out of the 78,075 evaluated (4.0%) were assigned at least one AIS90 injury code which changed in AIS98. For 1902 cases (2.4%) this change resulted in a difference in ISS between AIS90 and AIS98 (Table 4). The majority of cases which changed ISS had a difference of five points or less, and only 12 cases had a difference of 10 points or more (all resulting in a lower ISS using AIS98). The largest differences, of up to 50 points, were all

Table 2
List of AIS90 codes which changed localising or severity component in AIS98.

AIS90 code	Brief AIS90 descriptor	AIS98 equivalent
Changed localising component only; descriptor and severity component unchanged in AIS98		
442299.9	Thoracic cavity injury NFS	**442999.9**
630210.2	Cervical nerve root – avulsion NFS	**630262.2**
630212.2	Cervical nerve root – avulsion single	**630264.2**
630214.3	Cervical nerve root – avulsion multiple	**630266.3**
630299.2	Cervical nerve root – NFS	**630260.2**
630602.2	Lumbar nerve root or sacral plexus contusion	**630660.2**
630604.2	Lumbar nerve root or sacral plexus laceration – NFS	**630662.2**
630606.2	Lumbar nerve root or sacral plexus laceration – single	**630664.2**
630608.3	Lumbar nerve root or sacral plexus laceration – multiple	**630666.3**
630610.2	Lumbar nerve root or sacral plexus avulsion – NFS	**630668.2**
815002.2	Lower extremity degloving injury – toe(s) only one or more	**814002.2**
815004.2	Lower extremity degloving injury – thigh or calf	**814004.2**
815006.3	Lower extremity degloving injury – knee, ankle, sole of foot or entire extremity	**814006.3**
Changed severity component only; descriptor and localising component unchanged in AIS98		
160802.3	Unconscious on admission or initial observation – length NFS	**160802.2**
160804.4	Unconscious on admission or initial observation – length NFS – with neurological deficit	**160804.3**
441002.3	Heart contusion – NFS	**441002.1**
441004.3	Heart contusion – minor	**441004.1**
441099.3	Heart – NFS	**441099.1**
450210.1	Ribcage fracture NFS	**450210.2**
450260.4	Ribcage fracture with flail – NFS	**450260.3**
541020.3	Duodenum laceration – NFS	**541020.2**
541022.3	Duodenum laceration – no perforation	**541022.2**
650210.3	Unilateral cervical facet dislocation	**650210.2**
650410.3	Unilateral thoracic facet dislocation	**650410.2**
919404.6	High voltage electrical injury with cardiac arrest	**919404.5**

Table 3
List of AIS90 codes which required maps to AIS98, showing equivalent AIS98 codes for each AIS90 code.

AIS90 code	Brief AIS90 descriptor	AIS98 equivalent	Brief AIS98 descriptor
Changed injury descriptor – localising and severity component unchanged in AIS98			
541024.4	Duodenum – full thickness perforation	**541023.3**[b]	Duodenum laceration with $\geq$ 50–75% disruption
AIS90 codes removed; not present in the AIS98 codeset			
115299.9	Traumatic brain injury – NFS	**115099.9**	Closed head injury – NFS
140454.3	Cerebellum – oedema	**140450.3**	Cerebellum – brain swelling/oedema
140668.3	Cerebrum – brain oedema NFS	**140660.3**[a]	Cerebrum – brain swelling/oedema NFS
140670.3	Cerebrum – brain oedema mild	**140662.3**[a]	Cerebrum – brain swelling/oedema mild
140672.4	Cerebrum – brain oedema moderate	**140664.4**[a]	Cerebrum – brain swelling/oedema moderate
140674.5	Cerebrum – brain oedema severe	**140666.5**[a]	Cerebrum – brain swelling/oedema severe
150000.2	Skull fracture – NFS	**150400.2**[a]	Skull vault fracture – NFS
250802.2	Maxilla fracture – closed or open	**250800.2**	Maxilla fracture – NFS
420214.5	Major laceration thoracic aorta – with paraplegia not due to spinal cord trauma	**420210.5**	Major laceration thoracic aorta
450268.5	Rib cage fracture with flail – < 15 years old	**450260.3**[b]	Rib cage fracture with flail
541012.3	Duodenum contusion – with obstruction	**541010.2**[b]	Duodenum contusion
541026.5	Duodenum – full thickness perforation – involving pancreatic head, duct, ampulla	**541023.3**[b]	Duodenum laceration with $\geq$ 50–75% disruption
851802.2	Femur fracture – NFS – < 12 years old	**851800.3**[b]	Femur fracture – NFS
851806.2	Femur fracture – condylar – < 12 years old	**851804.3**[b]	Femur fracture – condylar
851816.2	Femur fracture – shaft – < 12 years old	**851814.3**[b]	Femur fracture – shaft
851820.2	Femur fracture – subtrochanteric – < 12 years old	**851818.3**[b]	Femur fracture – subtrochanteric
851824.2	Femur fracture – supracondylar – < 12 years old	**851822.3**[b]	Femur fracture – supracondylar
912010.3	3rd degree burn < 10% TBS – hand/face/genitalia involvement	**912008.2**[b]	3rd degree burn < 10% TBS
919602.1	Accidental hypothermia with temperature 34 degrees		*No equivalent code in AIS98*[c]
919604.2	Accidental hypothermia with temperature 32–33 degrees		*No equivalent code in AIS98*[c]
919606.3	Accidental hypothermia with temperature 30–31 degrees		*No equivalent code in AIS98*[c]
919608.4	Accidental hypothermia with temperature 28–29 degrees		*No equivalent code in AIS98*[c]
919610.5	Accidental hypothermia with temperature $\leq$ 27 degrees		*No equivalent code in AIS98*[c]

[a] More specific codes (of unchanged AIS severity) exist in AIS08.
[b] Code map also involves a change in injury severity.
[c] Equivalent codes exist in AIS08.

due to the modification of a severe electrocution injury from an AIS level 6 in AIS90 (for which an ISS of 75 is automatically assigned) to level 5 in AIS98 (resulting in an ISS of 25 unless additional injuries are present).

The agreement in overall ISS between AIS90 and AIS98 was high, with a kappa of 0.97; weighted kappa was similarly high (Table 4). There was statistically significant, but functionally negligible mean difference in ISS between the AIS90 and AIS98 codesets, with AIS98 cases being on average 0.006 ISS points higher.

Table 4
Differences in paired ISS for cases coded using AIS90 and mapped to AIS98. Summary statistics (with 95% confidence intervals) are shown.

Score difference	Number of cases (%)
ISS lower using AIS98	**885** (**1.1**)
8 points or greater	43
7 points	124
5 points	223
4 points	21
3 points	15
1 point	459
ISS unchanged using AIS98	**76,173** (**97.6**)
ISS higher using AIS98	**1017** (**1.3**)
1 point	298
2 points	21
3 points	76
4 points	16
5 points	594
8 points or greater	12
Total cases	**78,075**
Kappa coefficient (95%CI)	0.971 (0.970–0.972)
Quadratic weighted kappa coefficient (95%CI)	0.996 (0.995–0.996)
Mean difference between ISS pairs (95%CI)	0.006 points (0.001–0.012)

Effect of AIS version on major trauma classification

Of the 78,075 cases with calculated ISS, 8860 (11.3%) had an ISS > 15 in AIS90, and were classified as major trauma (Table 5). Agreement in major trauma status between AIS90 and AIS98 was very high (kappa 0.99). When AIS90 codes were mapped to AIS98, the number of cases classified as major trauma decreased by 68 (0.8%).

Injury types contributing to ISS change

The types of injuries contributing to ISS change, and the direction of those changes are shown in Table 6. The most common injury type resulting in ISS change was femoral fracture; out of 12,835 cases with one or more femoral fractures coded, 590 (4.6%; 95%CI, 4.3–5.0%) changed ISS in AIS98. A total of 2725 superficial injuries changed ISS body region between AIS90 and AIS98, with 195 having an AIS severity greater than 1. Due to the presence of other more severe injuries, though, changes to ISS body region did not affect ISS in the majority of cases. Only 863 cases with superficial injury had a different ISS in AIS98 as a result of these classification changes – 500 cases had a lower ISS, and 363 a higher ISS (Table 6).

The classification of duodenal injury changed in AIS98 to a greater extent than injury to any other structure. AIS classification was changed to align more closely with the Organ Injury Scales classification developed by the American Association for Surgery in Trauma.[3] Five of the eight codes for duodenal injury in AIS90 were removed or altered in AIS98, and the specificity available to particular types of duodenal injury were changed. However, these injuries were uncommon in practice, occurring in only 0.1% of the study population. Of the 98 cases assigned duodenal injury codes using AIS90, 43 required mapping to AIS98 equivalents; 37 cases had a lower calculated ISS in AIS98 as a result (Table 6). These cases accounted for 1.9% of all cases with a change in ISS.

Table 5
Effect of AIS version on number of patients classified as major trauma (ISS > 15). Summary statistics (with 95% confidence intervals) are shown.

		ISS calculated using AIS98	
		ISS < 15 (%)	ISS > 15 (%)
ISS calculated using AIS90	**ISS < 15**	69,195 (88.6)	20 (0.0)[a]
	ISS > 15	88 (0.1)	8772 (11.2)
Total patients		**78,075**	
Kappa coefficient (95%CI)		0.993 (0.992, 0.994)	
Total ISS > 15 patients using AIS90 (%)		8860 (11.3)	
Decrease in major trauma patients using AIS98 (%; 95%CI)		68 (0.8; 0.6, 1.0)	

[a] Rounded value is less than 0.05% of total.

Table 6
Type and body region of injuries resulting in ISS change between AIS90 and AIS98.

Score difference	Number of cases (%)
ISS lower using AIS98	**885 (1.1)**[a]
AIS body region change	**500**
Superficial penetrating injuries	491
Other superficial injuries	9
AIS severity score change	**391**[b]
Concussive closed head injury	66
Heart injury	53
Flail chest injury	76
Duodenum injury	37
Unilateral facet dislocation	17
Burn injury	143
Severe electrocution injury	6
ISS unchanged using AIS98	**76,173 (97.6)**
ISS higher using AIS98	**1017 (1.3)**[c]
AIS body region change	**363**
Superficial penetrating injuries	310
Other superficial injuries	53
AIS severity score change	**655**
Rib fracture	65
Femur fracture	590
Total cases	**78,075**

[a] Six cases had a decrease in ISS due to both body region and severity changes.
[b] Three cases were assigned two AIS90 codes which decreased in severity, and 2 cases were assigned three AIS90 codes which decreased in severity.
[c] One case had an increase in ISS due to both body region and severity changes.

During examination of the datasets, it was noted that one code from the AIS98 dictionary was listed in the AIS90 codeset used by QTR. The code, 851605.2, was used for a non-specific fibula fracture and was assigned 537 times in 530 cases. However, in AIS90 all isolated fibula fractures were assigned the same AIS severity level as this code. Consequently, the use of this code by the QTR did not affect ISS calculations in either AIS90 or AIS98.

Discussion

The feasibility of mapping between AIS versions has previously been demonstrated.[12] The map developed in this study provides AIS98 code equivalents for all AIS90 codes which changed or were not present in AIS98. The only exceptions were the five codes relating to accidental hypothermia. However, direct integration of this mapping tool with existing AIS98 to AIS08 mapping tools would enable complete, functionally accurate mapping of AIS90-coded datasets to the most current AIS version.

The AIS90 dictionary assigned codes to different body regions for ISS calculation, depending on how underlying and overlying injuries within a particular body region were associated. In instances where an 'internal' injury was relatively deep, or potentially unassociated with a superficial injury in the same body region, these rules would probably not be applied consistently. Simplification of ISS body region assignment rules in AIS98 and subsequent versions (where a given AIS code is always assigned to the same body region irrespective of associated injuries) has made this issue less relevant when mapping from AIS98 to AIS08.

Calculated ISS values across a population tend to be lower using AIS08 compared with previous AIS versions, with a resultant drop in the proportion of a population classified as major trauma estimated to be between 14% and 30%.[9,11,19–21] When mapping between AIS90 and AIS98, changes in ISS tended to be more evenly distributed, with comparable numbers of cases increasing and decreasing in ISS. As a result, the effect on major trauma classification is functionally negligible, with only a 0.8% decrease seen in major trauma cases in the current sample.

Due to the very large sample used in this study, there was a significant overall difference in ISS values between the AIS90 and mapped AIS98 datasets. However, the magnitude of this difference (with AIS98-based ISS being an average of 0.006 points higher) is not practically relevant. This test result was tempered by the magnitude of the effect size of the relationship (as measured using kappa), which was very high at 0.97.

Limitations

Apart from the exploratory analyses performed, the AIS90 to AIS98 map has not been formally validated (i.e., using double-coded data against which the results of AIS mapping could be compared). However, both the present study and that by Skaga et al.,[7] have established that the differences in overall population description between AIS90 and AIS98 are functionally negligible. Conversely, though, without this map 4.0% of cases (the 3102 cases who were assigned at least one AIS90 injury code changing in AIS98) could not be completely mapped to attain a more current injury severity estimate. It is unlikely that further double-coding work would be able to meaningfully distinguish between mapped and directly coded AIS98 datasets. If patients had been directly coded using AIS98, a number of injuries may have been assigned AIS98 codes which differed from those generated by mapping. The proportion of QTR patients classified as major trauma using AIS90 differed from the proportion classified using AIS98 by less than 1% (Table 6). Even if all of the injuries which could potentially differ in severity between mapped and directly coded AIS98 datasets did differ, almost two million patients would need to be double-coded to detect (with 80% power) a significant difference in the number patients classified as major trauma.

Comparison of Table 1 with a similar table in Skaga et al.,[7] shows some differences in the number of codes changing between, or available in AIS90 and AIS98. While our work identified 52 new codes in AIS98 and 23 AIS90 codes not present in AIS98, Skaga et al.,[7] identified only 51 new codes and 24 AIS90 codes that were removed. Also, their code count for AIS98 totalled 1339 codes, compared to 1341 codes in the current study, and other independent studies.[22,23] The reasons for these differences are unknown, although nomenclature differences for individual code changes between the two studies may have occurred. For example, Skaga et al.'s[7] evaluation of the complex duodenal code differences between AIS90 and AIS98 may have resulted in a different summary of the changes made. Alternatively, codeset differences have been found between different editions of the same AIS version.[24] It is possible that some minor differences may also exist between different copies of the AIS90 dictionary, or copies of the AIS98 dictionary. Such differences would not prevent mapping from being performed using AIS90-coded data, but need to be accounted for when electronically mapping between AIS versions.

In the present study, a small number of cases were assigned AIS90 codes for accidental hypothermia. These codes could not be mapped to AIS98, but had direct equivalents in AIS08. Many trauma registries do not include patients who have suffered isolated or mild hypothermia injuries.[25,26] As a result, the usefulness of mapping AIS codes relating to hypothermia may vary between datasets. Similarly, electrocution injuries – which had the greatest effect on ISS change – are specifically excluded by some registries.[26]

Finally, the QTR coded AIS90 superficial injuries to a consistent body region, irrespective of any associated injuries which may have been sustained. This differed from standard AIS90 coding practice, and may derive from the fact that the QTR was established around the time AIS98 was released. AIS98 coding rules for ISS body region assignment were used with the AIS90 codeset. However, the vast majority of codes assigned for superficial injuries on the QTR are of AIS severity level 1. At most, therefore, changes in the ISS body region to which these injuries are assigned will result in an ISS change of 1 point. Such a change is mathematically incapable of affecting major trauma classification around the ISS $>$ 15 threshold, and as a result the effects of this change are of little consequence across a severely injured population.

Conclusions

Abbreviated Injury Scale coding has served as the linchpin of trauma registry evaluations for decades. Severity adjustment using AIS-based scores is an important component of outcome comparisons between trauma systems, or over time within a population. In order to incorporate data coded using older AIS versions, the ability to electronically map datasets is essential. All of the AIS90 codes which were affected by ongoing AIS codeset development have been identified and mapped to AIS98 equivalents. This is an important step to enable ongoing, contemporary usage of existing AIS90-coded trauma registry data. The map developed in this study can be integrated with existing AIS mapping tools to facilitate the process of mapping from AIS90 to AIS08 via AIS98.

The calculated ISS for a small number of cases changed substantially between AIS90 and AIS98. However, the overall effect of mapping between AIS90 and AIS98 on the injury severity estimate of a large cohort was very small, and there was a very high level of agreement between the AIS90 and AIS98 datasets. This suggests that AIS90-coded data can be mapped to AIS08 via AIS98 using our mapping tool, with confidence in the functional accuracy of the resulting mapped dataset.

Conflict of interest statement

There were no external funding sources related to this study, and there were no conflicts of interest related to this study.

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2.3 SUMMARY

This study catalogued the small, but important differences between the 1990 and 1998 AIS versions, and developed a mapping tool which could be applied to an AIS 1990-coded dataset. This enabled the 4.0% of patients sustaining at least one code unique to the 1990 AIS to be subsequently mapped to the current 2008 AIS. With the development of this map, datasets from all currently used AIS versions can now be meaningfully compared and expressed using contemporary AIS nomenclature.

Applying this map to a dataset of nearly 80,000 patients from a state-wide trauma registry showed no practical difference between the 1990 and 1998 AIS versions in terms of the severity of an injured population as described using ISS. However, the majority of patients whose AIS codes required mapping (1,902 of 3,102; 61%) also had a change in their calculated ISS as a result. Where a threshold of ISS >15 was used to classify patients as major trauma, a number of patients' major trauma status was subsequently changed.

However, the study which was cited to refer to this ISS threshold was published in 1987. Since this study, the AIS has been revised four times and undergone substantial codeset change, particularly to the assessed severity of patients' injuries. As a result, maintaining comparability between patients across multiple AIS versions extends to more than using mapping to derive equivalent AIS datasets. A logical next step is establishing comparability between the summary scores derived from different AIS versions.

Chapter Three

Redefining Major Trauma

3.1 Overview of Chapter

The research described in Chapter Two provided the final link required to enable the comparison of AIS datasets using more recent AIS versions. For the past 30 years, an important use of AIS coding has been the classification of major trauma patients, using ISS greater than 15 as the sole criterion.[82,84] The stated rationale behind the selection of this threshold was equivalence to a 10% mortality rate.[82] In an era of trauma management where mortality was regarded as the primary endpoint, this was a sensible (if arbitrary) choice. However, the evidence behind the use of this ISS threshold is equivocal. Moreover, the extent of AIS codeset change since the ISS >15 criterion was developed and widely adopted means that this threshold may not have contemporary relevance.

The paper presented in this chapter reviews the rationale behind the historical use of the ISS >15 criterion to define a cohort of severely injured patients. A large dataset which had been initially coded using the 1998 AIS then mapped to the 2008 AIS using mapping tools was used to generate ISS using both 1998 and 2008 AIS data, and NISS using the 2008 AIS data. This data was used to identify and evaluate 2008 AIS-derived ISS and NISS alternatives performing similarly to a 1998 AIS-based ISS >15. In identifying these new thresholds, maintaining comparability in terms of the number of patients classified as major trauma was the primary aim. It was also important to assess the variability in mortality and in-hospital resource utilisation (as measured by the need for ICU or urgent surgery) using different ISS and NISS thresholds.

The following paper, 'Defining major trauma using the 2008 Abbreviated Injury Scale' was accepted for publication by Injury in July 2015, and published in print in January 2016. It is currently available online via the following link:

https://www.injuryjournal.com/article/S0020-1383(15)00411-8/fulltext.

3.2 Published Paper

Defining major trauma using the 2008 Abbreviated Injury Scale

Declaration for Thesis Chapter Three

Palmer CS, Gabbe BJ, Cameron PA. Defining major trauma using the 2008 Abbreviated Injury Scale. Injury 2016 Jan; 47(1):109-115. doi: 10.1016/j.injury.2015.07.003

In the case of Chapter Three, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Study conception and design; statistical analysis; development of tables and figures; manuscript drafting and revision	80%

The following co-authors contributed to the work. There are no student co-authors.

Name	Nature of contribution
Belinda Gabbe	Assisted with manuscript revision
Peter Cameron	Assisted with manuscript revision

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the candidate’s and co-authors' contributions to this work.

Candidate's signature	[redacted]	Date: 1 July 2019
Main supervisor's signature	[redacted]	Date: 1 July 2019

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Defining major trauma using the 2008 Abbreviated Injury Scale

Cameron S Palmer [a,b,*], Belinda J Gabbe [a,c], Peter A Cameron [a,d]

[a] Department of Epidemiology & Preventive Medicine, Monash University, Melbourne, Australia
[b] Trauma Service, Royal Children's Hospital Melbourne, Parkville, Australia
[c] Farr Institute - CIPHER, College of Medicine, Swansea University, Swansea, United Kingdom
[d] Emergency Medicine, Hamad Medical Corporation, Doha, Qatar

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ABSTRACT

Background: The Injury Severity Score (ISS) is the most ubiquitous summary score derived from Abbreviated Injury Scale (AIS) data. It is frequently used to classify patients as 'major trauma' using a threshold of ISS >15. However, it is not known whether this is still appropriate, given the changes which have been made to the AIS codeset since this threshold was first used. This study aimed to identify appropriate ISS and New Injury Severity Score (NISS) thresholds for use with the 2008 AIS (AIS08) which predict mortality and in-hospital resource use comparably to ISS >15 using AIS98.
Methods: Data from 37,760 patients in a state trauma registry were retrieved and reviewed. AIS data coded using the 1998 AIS (AIS98) were mapped to AIS08. ISS and NISS were calculated, and their effects on patient classification compared. The ability of selected ISS and NISS thresholds to predict mortality or high-level in-hospital resource use (the need for ICU or urgent surgery) was assessed.
Results: An ISS >12 using AIS08 was similar to an ISS >15 using AIS98 in terms of both the number of patients classified major trauma, and overall major trauma mortality. A 10% mortality level was only seen for ISS 25 or greater. A NISS >15 performed similarly to both of these ISS thresholds. However, the AIS08-based ISS >12 threshold correctly classified significantly more patients than a NISS >15 threshold for all three severity measures assessed.
Conclusions: When coding injuries using AIS08, an ISS >12 appears to function similarly to an ISS >15 in AIS98 for the purposes of identifying a population with an elevated risk of death after injury. Where mortality is a primary outcome of trauma monitoring, an ISS >12 threshold could be adopted to identify major trauma patients.
Level of evidence: Level II evidence—diagnostic tests and criteria.

Background

The Injury Severity Score (ISS) [1] is the oldest and best-known summary score derived from Abbreviated Injury Scale (AIS) [2] data. In the four decades since its initial development, other AIS-based summary scores have been developed [3–7], which are capable of outperforming ISS in predicting mortality following severe injury [5–8]. In spite of this, the simplicity and ubiquity of the ISS have resulted in its continued use (and recommendation) [9] in grouping or discriminating between trauma patients, and severity adjustment in comparisons of trauma populations. Importantly, the ISS has often been used to define a threshold (or cut-off value) for the classification of 'major trauma'—an otherwise arbitrary description of severely injured patients within a larger trauma patient population. This may be used as an inclusion criterion for a registry or research study population, or identifying a severely injured cohort within a more inclusive registry.

Since the 1980s, an ISS of greater than 15 has been the most commonly used threshold for defining major trauma [9,10]. Boyd et al. first described and adopted this threshold as predictive of 10% mortality [11]. However, although data from this study indicated that younger patients with ISS between 16 and 24 had a mortality of around 10%, overall mortality for patients with ISS >15 was more than 20% [12]. Also, mortality rates varied substantially depending on the body regions injured, the mechanism of injury and the specific ISS value evaluated [11]. Finally, it is not known

* Corresponding author at: The Royal Children's Hospital Melbourne, Flemington Rd, Parkville 3052, Australia. Tel.: +61 3 9345 4806; fax: +61 3 9345 6668.
E-mail addresses: cameron.palmer@rch.org.au (C.S. Palmer), belinda.gabbe@monash.edu (B.J. Gabbe), peter.cameron@monash.edu (P.A. Cameron).

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why a 10% mortality risk in particular was selected in establishing an ISS threshold.

The study data used by Boyd et al. [11] calculated ISS values from AIS codes using the 1985 version of the AIS. The magnitude and breadth of codeset changes introduced between the 1985 and 1998 releases (AIS98) were overall sufficiently small that the continued use of ISS >15 with AIS98-coded data remained reasonable. However, between AIS98 and the current AIS revision (AIS08, updated in 2008) [2] the AIS codeset was extensively modified and expanded, in part to reflect improvements in the diagnosis, management, classification and expected outcomes of injury. The resultant effects on patient classification in trauma registries are substantial and significant, and have been well-described [13–15]. As a result, even if an ISS >15 threshold corresponded to 10% mortality using older AIS versions, it may not satisfactorily differentiate between patients with lower and higher mortality rates when AIS08 is used to classify injuries [10,13].

Alternative thresholds based on NISS have also been proposed. The Utstein template [16], developed to standardise trauma monitoring across Europe, recommends the use of NISS >15 for registry inclusion. It has been suggested that this improves the sensitivity of patient capture without compromising specificity [16], although no studies have assessed this using AIS08. However, the NISS is equally susceptible to the classification differences between AIS versions which have affected the ISS [17]. Also, in spite of its limitations the ISS (and in particular the ISS >15 threshold) is still the most widely used trauma score [3], even within European registries [18].

Finally, although the AIS is associated with a range of trauma outcomes including mortality, in-hospital resource requirements and the extent of temporary or permanent disability and impairment [2], scores derived from AIS codes all used mortality as the sole or predominant outcome in their development [4–7]. As mortality rates from trauma have decreased with the introduction of trauma systems in developed countries, measurements of morbidity and the quality of survival (such as longer-term outcomes) have become more important [19,20]. As a result, although it is important to be able to link the use of existing scores such as the ISS across different AIS versions, such measures should not replace the development or evaluation of more contemporary, morbidity-based measures.

Objectives

The primary aim of this study was to identify ISS and NISS thresholds, based on AIS08-coding, which perform similarly to the earlier ISS > 15 threshold for AIS98-coded data in predicting mortality following trauma. This provided for two considerations—firstly, the need for more contemporary major trauma definitions (i.e., using the most current AIS version); secondly, the desire to maintain comparable numbers of patients classified as major trauma using both old and new thresholds. Secondary aims of interest were to evaluate the variability in mortality across a range of possible ISS and NISS values, and to assess ISS and NISS thresholds in measuring in-hospital service requirements.

Methods

The Victorian State Trauma Registry (VSTR) is a well-established registry collecting data on hospitalised major trauma, and many other severely injured patients managed in the Australian state of Victoria. Data are collected from all hospitals in the state which receive trauma patients. The VSTR was established in July 2001, with AIS98 used to code anatomical injuries sustained by patients until June 2010. AIS codes were assigned by trained coders, working both in Victorian hospitals and for the VSTR.

While AIS98 was being used by the VSTR, major trauma was defined within Victoria as not only patients who sustained injuries with an ISS >15, but also those who died, required more than 24 h in an ICU (with mechanical ventilation) or needed urgent surgical management. The registry also includes patients with a total hospital length of stay greater than 72 h, while excluding some isolated facial, limb or superficial injuries and isolated femoral neck fractures. Complete inclusion and exclusion criteria for the VSTR are published elsewhere [21].

Data for all patients meeting VSTR inclusion criteria over the 9 year period from July 2001 to June 2010 were used in this analysis. Using a validated mapping tool [22,23], equivalent AIS08 codes were derived from the existing AIS98 codes, together with free text injury descriptions where appropriate. Two ISS values were calculated for each patient using AIS98 and AIS08 codes (termed ISS98 and ISS08); NISS scores were also calculated using AIS08 data (termed NISS08). These were combined with in-hospital mortality data to derive cumulative mortality rates at or above each possible ISS and NISS value. For both ISS08 and NISS08 data, thresholds were selected which returned a similar mortality rate to the ISS > 15 threshold as used with AIS98 data.

The need for ICU admission (with or without mechanical ventilation) or urgent surgery (using VSTR criteria) [21] were also obtained for secondary comparisons as proxy measures of in-hospital resource use. Contingency tables were generated, and McNemar's chi-square test used to compare the AIS08-based thresholds in terms of their ability to correctly classify patients who died or needed ICU or urgent surgery. For each outcome measure, the proportions of patients who were correctly classified (i.e., either a 'true positive' or a 'true negative' within each contingency table) were also calculated, and differences in these between the AIS08-based thresholds were evaluated. Confidence intervals were calculated at the 95% level.

Results

Data for 38,535 severely injured patients were extracted from the VSTR. Coded using AIS98, these patients sustained a total of 153,449 injuries; following mapping, 158,284 AIS08 codes were derived due to injury classification differences (particularly relating to chest and pelvic injuries) between AIS98 and AIS08 [22]. ISS98, ISS08 and NISS08 scores were calculated for 37,760 patients. The remaining patients either sustained injury types which were not codeable in both AIS98 and AIS08 (such as drowning) or sustained isolated non-specific (AIS level '9') injuries for which summary scores could not be calculated.

The age and gender profile of VSTR patients is shown in Fig. 1. Below the age of 80 years, more males than females were injured in every age group. The incidence of trauma amongst males peaked in the 20–24 years age group, while for females the peak incidence was seen in patients aged 80–84 years.

Overall population descriptions using ISS and NISS

Of patients with available summary scores, 2340 patients died. This gave a crude mortality rate for the VSTR population of 6.2% (95% CI 6.0, 6.4%). There were 15,757 patients with ISS98 >15 (41.7% of the dataset; 95% CI 41.2, 42.2%); of these, 1799 patients (11.4%; 95% CI 10.9, 11.9%) died.

Fig. 2 shows mortality rates for a range of moderate to severe individual ISS and NISS values calculated from VSTR data. Below scores of 25, the mortality risk associated with specific ISS08 and NISS08 values remained low—as low as 3.1% for an ISS08 of 19, and 1.9% for a NISS08 of 17. A 10% mortality level was not seen for any of the AIS-derived scores until values of 25 or higher.

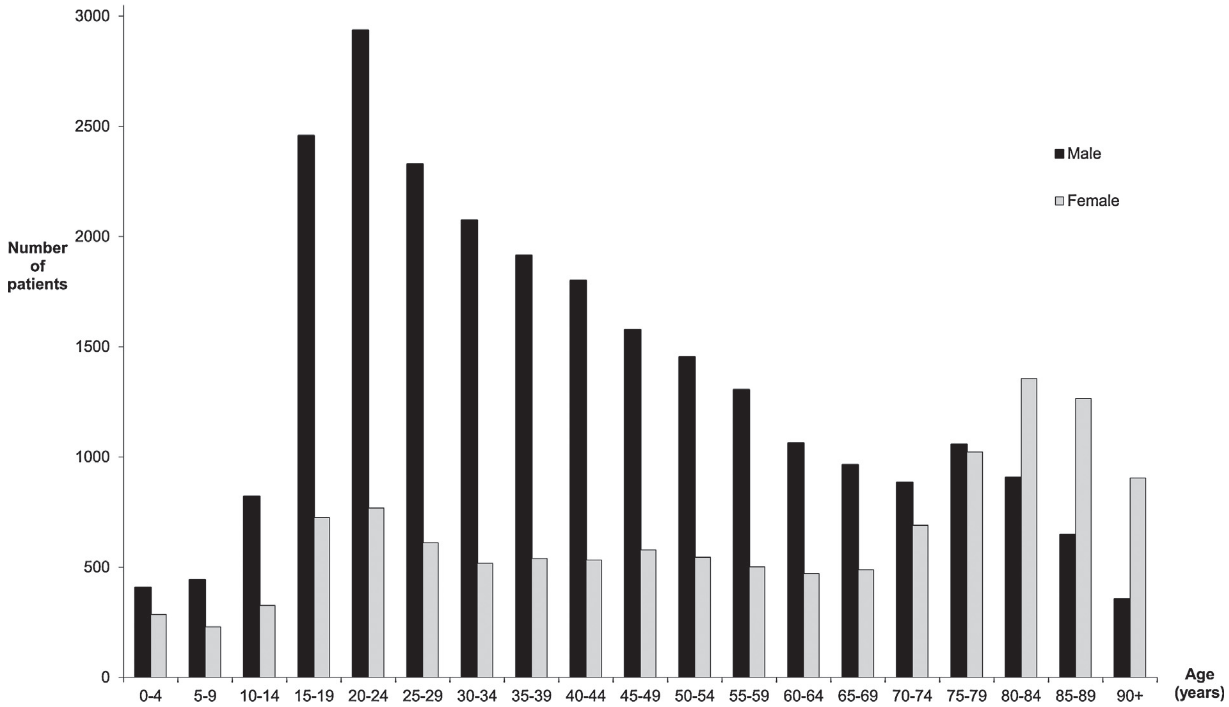

Fig. 1. Age and gender breakdown of the 37,760 VSTR patients included in the study.

Fig. 3 demonstrates the cumulative mortality above theoretical ISS thresholds for VSTR data using AIS98-based and AIS08-based scores. In some instances, cumulative mortality rates paradoxically decreased with increasing ISS and NISS values, as mortality rate for individual values (such as ISS or NISS of 27; Fig. 2) were comparatively low. NISS08 scores returned similar cumulative mortality rates to ISS98, while ISS08 mortality rates calculated for each threshold value were higher. For AIS08-based scores, the 11.4% mortality rate seen amongst ISS98 >15 patients (indicated in the figure by a dashed line) was most closely matched by an ISS08 threshold of >12 (11.6%, capturing 14,729 patients) and a NISS08 threshold of >16 (11.1%, capturing 15,472 patients). However, for the purposes of further evaluation a NISS08 threshold of >15 (11.0% mortality, capturing 16,074 patients) was used, as the differences were small and this threshold has been recommended in

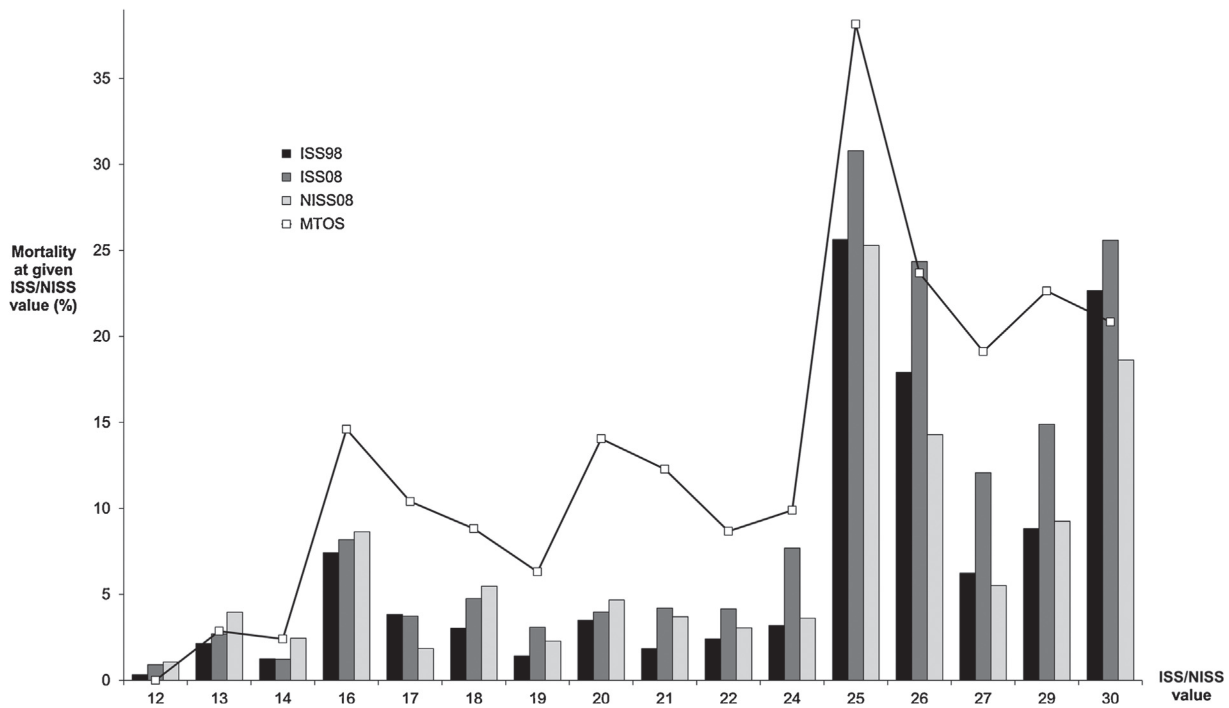

Fig. 2. Mortality rates for individual ISS and NISS values, calculated from VSTR data using AIS98-based and AIS08-based scores. Major Trauma Outcome Study data [12] is shown for comparison. ISS and NISS values below 12 and above 30 are not shown.

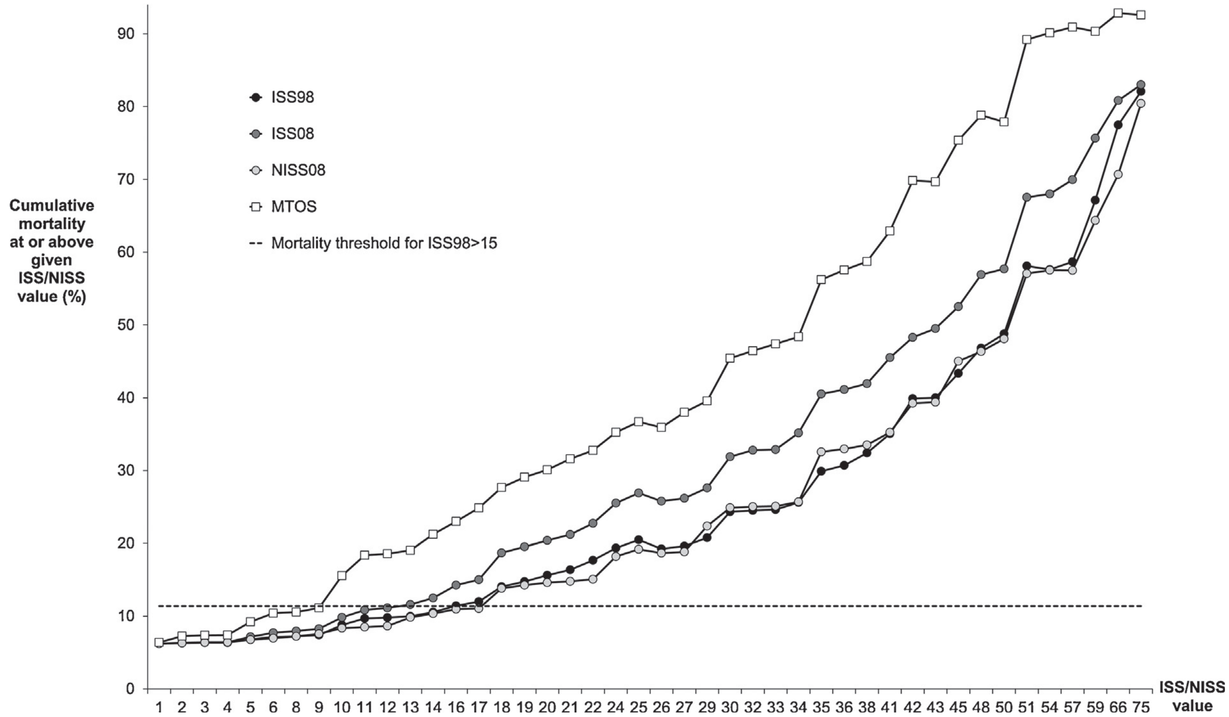

Fig. 3. Mortality rates at or above theoretical ISS and NISS thresholds for VSTR data, using AIS98-based and AIS08-based scores. Major Trauma Outcome Study data [12] is shown for comparison. Note that not all ISS/NISS values are mathematically obtainable.

the literature [15]. Compared with an ISS98 >15, these thresholds resulted in a decrease in the number of patients classified as major trauma of 6.5% for ISS08 >12 (95% CI 6.1, 6.9%; *n* = 1028), and an increase of 2.0% for NISS >15 (95% CI 1.8, 2.2%; *n* = 317).

In-hospital outcome prediction using ISS and NISS thresholds

Table 1 shows the number of patients who were captured using both the ISS08 >12 and NISS08 >15 thresholds, for mortality and the need for ICU or urgent surgery. Table 2 illustrates the precision

Table 1
Contingency tables for prediction of death, the need for ICU or the need for urgent surgery (OR) for AIS98-based and AIS08-based summary score thresholds evaluated. Row percentages are provided.

Death

Using an ISS98 >15 threshold

	Died	Survived	Total
ISS98 <15	541 *2.5%*	21,462 *97.5%*	22,003
ISS98 >15	1799 *11.4%*	13,958 *88.6%*	15,757
Total	2340	35,420	37,760

Using an ISS08 >12 threshold

	Died	Survived	Total
ISS08 ≤12	634 *2.8%*	22,397 *97.2%*	23,031
ISS08 >12	1706 *11.6%*	13,023 *88.4%*	14,729
Total	2340	35,420	37,760

Using a NISS08 >15 threshold

	Died	Survived	Total
NISS08 <15	577 *2.7%*	21,109 *97.3%*	21,686
NISS08 >15	1763 *11.0%*	14,311 *89.0%*	16,074
Total	2340	35,420	37,760

Need for ICU

Using an ISS98 >15 threshold

	ICU	No ICU	Total
ISS98 <15	2312 *10.5%*	19,691 *89.5%*	22,003
ISS98 >15	7058 *44.8%*	8699 *55.2%*	15,757
Total	9370	28,390	37,760

Using an ISS08 >12 threshold

	ICU	No ICU	Total
ISS08 ≤12	2570 *11.2%*	20,461 *88.8%*	23,031
ISS08 >12	6800 *46.2%*	7929 *53.8%*	14,729
Total	9370	28,390	37,760

Using a NISS08 >15 threshold

	ICU	No ICU	Total
NISS08 <15	2263 *10.4%*	19,423 *89.6%*	21,686
NISS08 >15	7107 *44.2%*	8967 *55.8%*	16,074
Total	9370	28,390	37,760

Need for urgent surgery

Using an ISS98 >15 threshold

	Surgery	No surgery	Total
ISS98 <15	1862 *8.5%*	20,141 *91.5%*	22,003
ISS98 >15	5157 *32.7%*	10,600 *67.3%*	15,757
Total	7019	30,741	37,760

Using an ISS08 >12 threshold

	Surgery	No surgery	Total
ISS08 ≤12	1880 *8.2%*	21,151 *91.8%*	23,031
ISS08 >12	5139 *34.9%*	9590 *65.1%*	14,729
Total	7019	30,741	37,760

Using a NISS08 >15 threshold

	Surgery	No surgery	Total
NISS08 <15	1629 *7.5%*	20,057 *92.5%*	21,686
NISS08 >15	5390 *33.5%*	10,684 *66.5%*	16,074
Total	7019	30,741	37,760

AIS98, Abbreviated Injury Scale (1998 Update); AIS08, Abbreviated Injury Scale (2008 Update); ISS, Injury Severity Score, calculated using 1998 (ISS98) and 2008 AIS versions (ISS08); NISS, New Injury Severity Score, calculated using AIS08 (NISS08).

Table 2
Summary and comparative scores for three ISS and NISS thresholds evaluated. Data for ISS08 >12 and NISS08 >15 thresholds are based on data from Table 1 Brackets show 95% confidence intervals (CI) unless otherwise stated. McNemar's test (*df* = 1 throughout) used to compare AIS08-based thresholds only.

	Summary score percentage (95% CI)		
	ISS98 >15	ISS08 >12	NISS08 >15
Death			
Sensitivity	76.9 *(75.1, 78.5)*	72.9 *(71.1, 74.7)*	75.3 *(73.6, 77.0)*
Specificity	60.6 *(60.1, 61.1)*	63.2 *(62.7, 63.7)*	59.6 *(59.1, 60.1)*
Correctly classified (CC)	61.6 *(61.1, 62.1)*	63.8 *(63.3, 64.3)*	60.6 *(60.1, 61.1)*
Difference in CC between ISS08 >12 and NISS08 >15	–	3.3 *(3.0, 3.5)*	
McNemar's X^2 test *(p-value)*	–	493.4 *(<0.0001)*	
Need for ICU			
Sensitivity	75.3 *(74.4, 76.2)*	72.6 *(71.7, 73.5)*	75.8 *(75.0, 76.7)*
Specificity	69.4 *(68.8, 69.9)*	72.1 *(71.5, 72.6)*	68.4 *(67.9, 69.0)*
Correctly classified	70.8 *(70.4, 71.3)*	72.2 *(71.7, 72.6)*	70.3 *(69.8, 70.7)*
Difference in CC between ISS08 >12 and NISS08 >15	–	1.9 *(1.6, 2.2)*	
McNemar's X^2 test *(p-value)*	–	174.0 *(<0.0001)*	
Need for urgent surgery			
Sensitivity	73.5 *(72.4, 74.5)*	73.2 *(72.2, 74.2)*	76.8 *(75.8, 77.8)*
Specificity	65.5 *(65.0, 66.0)*	68.8 *(68.3, 69.3)*	65.2 *(64.7, 65.8)*
Correctly classified	67.0 *(66.5, 67.5)*	69.6 *(69.2, 70.1)*	67.4 *(66.9, 67.9)*
Difference in CC between ISS08 >12 and NISS08 >15	–	2.2 *(1.9, 2.5)*	
McNemar's X^2 test *(p-value)*	–	231.4 *(<0.0001)*	

AIS08, Abbreviated Injury Scale (2008 Update); ISS, Injury Severity Score, calculated using 1998 (ISS98) and 2008 AIS versions (ISS08); NISS: New Injury Severity Score, calculated using AIS08 (NISS08); Defining major trauma using the 2008 Abbreviated Injury Scale.

values calculated from these tables. Both tables show (for comparison) the same values calculated using an ISS98 >15 threshold. For each of the three measures of severity (mortality, ICU or urgent surgery), an ISS08 >12 threshold was less sensitive, but more specific than NISS08 >15. Overall, the ISS08 >12 threshold correctly classified significantly more patients for each measure of severity than NISS08 >15.

Discussion

In the present study, an ISS >12 threshold used with AIS08 data captures a similar number of patients, with a comparable overall mortality rate, to the ISS >15 threshold used with earlier AIS versions. This threshold also correctly classified more patients than a NISS >15 in evaluating the risk of death or the need for ICU admission or urgent surgery. In addition, the ISS remains the more widely used measure worldwide, allowing for easier adoption of the updated ISS >12 threshold. To follow the recommendation made by Boyd et al. [11] where mortality is the primary outcome of interest, an ISS or NISS threshold of >24 would be appropriate when using AIS08 data, as mortality rates for each specific ISS and NISS value below this level are low (Fig. 2). However, this would exclude many patients with potentially life-threatening or disabling injuries, and would consequently impede trauma system performance monitoring.

The decrease in patients meeting a given ISS threshold when updating from AIS98 to AIS08 is well-established [13–15]. The use of an ISS >12 threshold in AIS08 still results in a small decrease in the number of patients classified as major trauma, calculated at 6.5% in the present study. However, lowering the ISS threshold further would include many more patients with a very low mortality (Fig. 2). Also, it should be stressed that the intent of the present study was not to determine an 'optimum' AIS08-based threshold for ISS or NISS using any of the binary-classified outcome measures employed (such as could be obtained using ROC analysis [10]).

Discriminative measures are of limited use with AIS-based scores. In the present study, about one quarter of the patients who died following injury had calculated ISS and NISS values below the thresholds evaluated. This suggests that severity scores should not be used as the sole inclusion criterion for a trauma registry. In addition to patients meeting an ISS threshold, the VSTR categorises any patient who dies, requires urgent internal surgery or requires a substantial period of intensive care treatment with mechanical ventilation as major trauma, irrespective of their ISS [21]. Such additional criteria can mitigate the decrease in major trauma numbers resulting from adopting AIS08, as well as identifying patients at high risk of death or requiring high levels of in-hospital resources [13,17].

The present study demonstrated a variable, non-linear relationship between the AIS summary scores evaluated and outcomes such as death (Fig. 2); such variability has been documented previously [10]. This is not surprising, as the ISS was developed in an attempt to better correlate injury severity with mortality while adjusting for multiple injuries [1]. More than 40 years after its initial development, the ISS remains by far the most commonly used trauma score in spite of its many limitations [3]. It is possible that alternative methods of summarising the detailed information inherent in AIS08 may be better able to predict outcomes following injury [18]. This is particularly relevant when considering outcomes beyond mortality or acute care, although such evaluations were beyond the scope of the present study [19]. However, it seems reasonable to suggest that as long as mortality remains the primary outcome of trauma evaluation the ISS is likely to be widely retained. With this in mind, the results of the current study suggest that using ISS >12 will at least maintain consistency regarding how severely injured patients with an elevated risk of death are classified in trauma registries. To this end, further evaluation of existing or novel AIS summary scores with AIS08-coded data – particularly with the prediction of longer-term or functional outcomes as a goal – should be regarded as a priority.

Finally, there is a need for standardisation of trauma terminology extending beyond the term 'major trauma' evaluated in the current study. A recent study [9] proposed defining 'polytrauma' (a term essentially synonymous with 'multitrauma' in other countries) as patients having AIS >2 injuries in at least two body regions, as well as meeting criteria relating to age or pathologic or physiological change. The authors also aimed to link definitions by suggesting that the overall mortality risk for polytrauma should be double that of major trauma [9]. However, the study employed a high estimate of 15% mortality for major trauma, despite the reference study used [24] showing less than 10% mortality when a modern trauma service was in place. Also, the data used related to patients injured between 1993 and 2010 [9]. Without mentioning AIS version adjustment, most or all of this data may have been coded using obsolete versions of the AIS, rendering the mortality estimates from this study invalid when using the contemporary AIS08 to code injuries.

Limitations

This study evaluated the trauma population of a single region. The VSTR maintains complete coverage of all levels of the hospital system in the state of Victoria, which has a population of about five million people. It captures all hospital-admitted major trauma, and the majority of other patients with substantial management requirements. As such, it is less likely to be susceptible to systematic biases affecting registries which focus primarily on patients receiving care at larger trauma centres. As a result, findings from VSTR data are likely to be applicable to populations with similar trauma epidemiology—specifically, high-income countries with relatively low rates of penetrating trauma. Mortality estimates in the current study are therefore likely to be accurate for higher ISS values. Below ISS 15, though, the proportion of injury not captured by the VSTR is likely to rise steeply. For example, the incidence of death after sustaining injuries with ISS 1 (including minor superficial injury) in the wider population would be essentially zero, but in the VSTR population it was 2.0% (26 of 1272 patients) due largely to the presence of elderly and significantly co-morbid patients. However, because the VSTR captures a large number of severely injured patients not meeting any of the specific criteria for 'major trauma' – including patients with multiple moderate injuries and with a moderate length of stay – it is likely that the VSTR has captured a substantial proportion of trauma with ISS98 below (but close to) 15. Also, less than 1% of patients have an increase in their ISS when coding injuries using AIS08 instead of AIS98 [13]. The likelihood that substantial numbers of relevant, severely injured Victorian patients have been 'missed' by the VSTR inclusion criteria used therefore remains very low. Finally, due to the way in which the McNemar's chi-square tests are calculated, the significance of the results presented in Table 2 – at least for mortality and urgent surgery, which are both Victorian major trauma criteria – would not have changed with the inclusion of additional patients with moderate ISS or NISS who did not meet either of these criteria. However, the effect of including additional patients who may have required short stays in ICU on the results of the present study remains unknown.

The present study used AIS08 data which was mapped from AIS98 codes using validated tools [22,23]. Although the published validation suggested that the mapped data produced ISS values which agreed very closely with ISS from directly-coded AIS08 data – and across an entire trauma registry are likely to be functionally indistinguishable – at an individual level up to 25% of patients may have some difference in ISS [22].

In the period valuated, there were 775 VSTR patients (amounting to 2.0% of the VSTR) whose data could not be used in the present study, as complete ISS/NISS scores could not be obtained using both the AIS98 and AIS08 codesets. Patients who only sustained injuries coded as level 9 (non-specific) in either codeset were included in this group. Using VSTR criteria, 193 of these patients were classified as major trauma patients by virtue of death or the need for ventilation in ICU, but did not have adequate injury coding due to rapid death after injury, or a mechanism of injury such as drowning or hanging asphyxia (which were not codeable in AIS98, and are frequently excluded from trauma registries). As patients who died soon after injury are intuitively more likely to have sustained severe injuries and thus high ISS or NISS, it is believed that the exclusion of these patients is unlikely to have affected the findings of the present study.

Conclusion

When coding injuries using AIS08, an ISS >12 threshold appears to function similarly to an ISS >15 using AIS98 in identifying a population with an elevated risk of death or the need for substantial hospital management after injury. A NISS threshold of >15 performs similarly, although with some loss of overall predictive value. However, the closer association between individual NISS08 and ISS98 scores compared with ISS08 (as seen in Fig. 3) suggests that NISS08 may have some utility for applications other than defining major trauma. The AIS08-based thresholds used were selected based on similar mortality prediction [11], overall number of patients classified as 'major trauma' and prior use in the literature [16].

As a result, while trauma registries continue to widely use older aggregate scores such as the ISS, an ISS >12 threshold remains the simplest way to maintain reasonable consistency in major trauma classification when adopting AIS08 after using ISS >15 with earlier AIS versions. This threshold has already been adopted by a number of Australian state trauma registries [20,25], although this study is the first time that the use of this threshold has been empirically validated.

However, the development or validation of other tools which better reflect the severities assigned to injuries in AIS08 should be regarded as a priority. To this end, the results of the present study provide for a simple, temporary 'stop-gap' measure for consistently identifying major trauma. Ideally, the development of modern outcome prediction tools should involve the evaluation of outcomes other than mortality or in-hospital morbidity, such as functional or quality of life outcomes following severe trauma.

Conflict of interest

Authors declare that there are no external funding sources related to this study, and that there are no conflicts of interest related to this study.

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3.3 SUMMARY

The AIS codeset changed comparatively little between the 1985 and 1998 versions. Even so, improvements in trauma care have reduced the relevance of the ISS >15 criterion when applied strictly to an outcome of mortality. In the present study, an ISS >15 criterion applied to the 1998 AIS-coded data in the present study was associated with far lower mortality than in the 1987 paper where this threshold was first suggested.

Using a large dataset of over 37,000 severely injured patients, a 1998 AIS-derived ISS >15 threshold was best approximated by an ISS >12 threshold, or a NISS >15 threshold when 2008 AIS was used. The ISS >12 threshold was more specific for, and correctly classified more patients who died or required ICU or urgent surgery than NISS >15. As such - and given that the ISS remains in more widespread use than the NISS - the adoption of an ISS >12 threshold for major trauma classification when using the 2008 AIS was recommended.

The use of either 2008 AIS-derived threshold resulted in a minor change in the number of patients classified as major trauma. However, the magnitude of these changes were far smaller than the decrease in classified major trauma patient numbers resulting from AIS version change to the current 2008 AIS. As such, the adoption of an ISS >12 threshold with 2008 AIS data maintains reasonable consistency in the setting of AIS version change. However, the present study stressed that this should be regarded as a 'stop-gap' measure, pending the development of tools which can make better use of the larger AIS codeset currently in use.

It is important to maintain comparability between AIS versions for existing uses of AIS data. Because of the ubiquity of the ISS in current evaluations of trauma severity and risk-adjustment, the present study is therefore relevant. However, in developed trauma systems it is no longer appropriate to focus only on mortality or in-hospital measures of as primary outcomes following severe injury. As such, the development of newer 2008 AIS-based outcome measures is desirable. Ideally, these should focus on measuring or predicting functional outcomes in survivors of severe trauma, beyond their acute hospital management.

Chapter Four
Reviewing the Functional Capacity Index

4.1 Overview of Chapter

The work presented in the preceding two chapters enabled the comparison of both AIS-coded datasets and AIS summary scores which had been derived from different AIS versions. As such, the aim for the first aspect of this thesis had been addressed, and the second specific aim - relating to the prediction of functional outcomes amongst survivors of severe trauma - became relevant.

The severity levels associated with AIS codes are known to be weighted towards mortality. As a result, the FCI was developed (and later re-developed) alongside two revisions of the AIS codeset to provide alternative severity scores which were designed to reflect anticipated functional outcomes 12 months following a trauma event.

The paper presented in this chapter is a narrative review. The paper reviewed the development, structure and validation of both versions of the FCI - the first using the 1990 AIS codeset, and the second released alongside the 2008 AIS. The strengths and limitations of the FCI were reviewed and discussed, with particular attention paid to how identified limitations of the original FCI were addressed in the development of the 2008 FCI. Studies which had used the FCI to predict functional outcomes were also identified and discussed.

The following paper, 'A review of the revised Functional Capacity Index as a predictor of 12 month outcomes following injury' was accepted for publication by Injury in January 2017, and published in print in March 2017. It is currently available online via the following link:

https://www.injuryjournal.com/article/S0020-1383(17)30006-2/fulltext

4.2 Published Paper

A review of the revised Functional Capacity Index as a predictor of 12 month outcomes following injury

Declaration for Thesis Chapter Four

Palmer CS, Cameron PA, Gabbe BJ. A review of the revised Functional Capacity Index as a predictor of 12 month outcomes following injury. Injury 2017 Mar; 48(3):591-598. doi: 10.1016/j.injury.2017.01.006

In the case of Chapter Four, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Study conception and design; literature search and paper retrieval; development of tables and figures; manuscript drafting and revision	80%

The following co-authors contributed to the work. There are no student co-authors.

Name	Nature of contribution
Peter Cameron	Study conception and manuscript revision
Belinda Gabbe	Study conception and manuscript revision

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the candidate's and co-authors' contributions to this work.

Candidate's signature	[redacted]	Date: 1 July 2019
Main supervisor's signature	[redacted]	Date: 1 July 2019

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Review

A review of the revised Functional Capacity Index as a predictor of 12 month outcomes following injury

Cameron S. Palmer[a,b,*], Peter A. Cameron[a,c], Belinda J. Gabbe[a,d]

[a] Department of Epidemiology & Preventive Medicine, Monash University, Melbourne, Australia
[b] Trauma Service, Royal Children's Hospital Melbourne, Parkville, Australia
[c] Emergency Medicine, Hamad Medical Corporation, Doha, Qatar
[d] Farr Institute – CIPHER, College of Medicine, Swansea University, Swansea, United Kingdom

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ABSTRACT

The measurement of functional outcomes following severe trauma has been widely recognised as a priority for countries with developed trauma systems. In this respect, the Functional Capacity Index (FCI), a multi-attribute index which has been incorporated into the most recent Abbreviated Injury Scale (AIS) dictionary, is potentially attractive as it offers 12-month functional outcome predictions for patients captured by existing AIS-coded datasets.

This review paper outlines the development, construction and validation of the predictive form of the FCI (termed the pFCI), the modifications made which produced the currently available 'revised' pFCI, and the extent to which the revised pFCI has been validated and used.

The original pFCI performed poorly in validation studies. The revised pFCI does not address many of the identified limitations of the original version, and despite the ready availability of a truncated version in the AIS dictionary, it has only been used in a handful of studies since its introduction several years ago. Additionally, there is little evidence for its validity.

It is suggested that the pFCI should be better validated, whether in the narrow population group of young, healthy individuals for which it was developed, or in the wider population of severely injured patients. Methods for accounting for the presence of multiple injures (of which two have currently been used) should also be evaluated.

Many factors other than anatomical injury are known to affect functional outcomes following trauma. However, it is intuitive that any model which attempts to predict the ongoing morbidity burden in a trauma population should consider the effects of the injuries sustained. Although the revised pFCI potentially offers a low-cost assessment of likely functional limitations resulting from anatomical injury, it must be more rigorously evaluated before more comprehensive predictive tools can be developed from it.

Contents

* Corresponding author at: The Royal Children's Hospital Melbourne, Flemington Rd, Parkville, 3052, Australia.
E-mail addresses: cameron.palmer@rch.org.au (C.S. Palmer), peter.cameron@monash.edu (P.A. Cameron), belinda.gabbe@monash.edu (B.J. Gabbe).

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Background

Forty five years after its introduction, the Abbreviated Injury Scale (AIS) [1] remains the predominant method for scoring the severity of anatomical injury. The scaled severities assigned to each code in the AIS were originally intended to reflect more than mortality [2]. However, it has been known (and re-iterated) since the 1970s that AIS severities are weighted towards the likelihood of mortality [2–5]. In high income countries where mature trauma systems have brought about significant reductions in mortality, there has been a shift away from focusing on mortality-driven outcomes towards quantifying the extent of morbidity amongst the large proportion of trauma victims who survive their injuries [6–9]. Measurement of functional outcomes was identified as a priority for trauma systems research nearly 20 years ago [10,11], but most registries still do not routinely collect outcomes beyond death or hospital-based severity proxies such as length of stay [8,11,12].

The Functional Capacity Index (FCI) [13–15] is “a multi-attribute index that maps anatomic descriptions . . . of injury [from AIS codes] into scores that reflect the likely extent of functional limitations or reduced capacity at one year post-injury” [13]. First developed in the mid-1990s, the FCI was subsequently revised alongside the AIS, and was eventually incorporated into the current (2008) version of the AIS dictionary [4,16]. As such, the FCI is potentially attractive as a readily available alternative severity predictor using existing AIS-coded datasets.

This paper aims to review the construction and validation of the predictive Functional Capacity Index (termed pFCI), the modifications made to the ‘original' version which produced the current ‘revised' pFCI and it's truncated version used in the 2008 AIS dictionary (termed pFCI08), and the extent to which this revised tool has been validated and used. This includes appraising the extent to which the revised versions have addressed or overcome limitations identified in the original pFCI. The primary objective of this process is to inform future research using the revised pFCI, and the truncated pFCI08.

Review strategy

The current review involved searches of the general term ‘functional capacity index' and the acronym ‘FCI' in titles or abstracts of papers referenced in the Scopus, CINAHL, Web of Science and PubMed databases. This was initially performed in late 2015, and updated in September 2016 with the addition of Ovid Embase and Google Scholar. Results not related to the FCI instrument (such as other uses of the acronym) were discarded. Scopus was also used to search for papers referencing critical studies in the development [13,14] and validation [17–20] of both versions of the FCI. Once all relevant papers were obtained, their reference lists were also reviewed for relevant citations not found elsewhere.

Development and validation of the original pFCI

Construction of the original FCI

The pFCI is an aggregated score, calculated across ten weighted ‘dimensions' of function (Table 1). The developers of the original pFCI formulated descriptions of different levels of function within each dimension; an example of these (for the ambulation dimension) is shown in Table 2 [14]. An expert panel was then used to estimate, for each code in the 1990 AIS dictionary, the most likely level of function (in each dimension of function) which would be expected to result 12 months after the injury was sustained [13,14]. The weights for each dimension, and for each level of function within those dimensions, were derived from the responses of a convenience sample comprising both those familiar with trauma (as staff or patients) and lay people (a mixture of blue- and white-collar workers and college students). For each AIS code, the expected level and dimension scores were mathematically combined to produce an expected overall level of function 12 months following injury. An example of this process (for an AIS spinal injury code) can be seen in Fig. 1.

Table 1
Dimensions and levels of function comprising the original FCI [12,13].

Dimension of function	Levels of function	Dimension weighting (percentage)	Expected percentage loss of function for each level of function						
			A (no limitation)	B	C	D	E	F	G
Eating	3	75.2	0.0	38.2	100.0	–	–	–	–
Excretory function	4	74.0	0.0	43.1	74.6	100.0	–	–	–
Sexual function	3	45.7	0.0	49.7	100.0	–	–	–	–
Ambulation	6	66.6	0.0	21.8	45.6	68.5	80.6	100.0	–
Hand and arm	6	75.0	0.0	31.0	57.9	54.3	81.0	100.0	–
Bending and lifting	4	49.4	0.0	29.5	64.6	100.0	–	–	–
Visual	7	41.3	0.0	47.3	34.7	51.8	80.3	89.0	100.0
Auditory	5	34.8	0.0	19.6	36.5	66.8	100.0	–	–
Speech	4	68.5	0.0	29.6	65.6	100.0	–	–	–
Cognitive	6	100.0	0.0	26.7	49.9	78.2	92.5	100.0	–

Table 2
Brief descriptions of the six levels of function used for FCI assessment within the ambulation dimension of function [14].

Level	Description	Expected percentage loss of function at level
A	No limitations	0.0
B	Independent without device, but has minor limitations in amount of running or vigorous walking appropriate to age	21.8
C	Independent but may require device; takes more than reasonable amount of time to walk and/or climb stairs	45.6
D	Can walk a minimum of 150 feet but only with assistance	68.5
E	Amount of walking generally limited to 150 feet with or without assistance	80.6
F	Severe difficulty in standing and walking a minimum of 50 feet, including not being able to do it at all	100.0

In developing the original pFCI, the assessment of expected functional loss in each dimension for each AIS injury was governed by four assumptions [13,14,21]:

i the individual survives the injury;
ii the individual is aged between 18 and 34 years and has no prior comorbidities;
iii the acute care and rehabilitation received is appropriate and timely; and
iv the injury described is the only injury sustained.

Despite these underlying assumptions, studies have used the pFCI to predict outcomes in wider trauma patient populations. When applied to patients with multiple injuries, prediction of functional loss is often evaluated using the pFCI by assuming that the worst injury (in terms of predicted functional loss) is equivalent to the overall functional loss [14,15].

As intended, the pFCI has been the primary use of FCI in published studies, estimating the predicted functional loss in populations of injured patients [15,22–28]. In particular, the pFCI has been used in studies evaluating large ICD-coded population datasets [22,23,26,27] or crash databases [15,24,25,28,29] where patient follow-up and outcome assessment is unfeasible. Other applications for the FCI have been suggested, developed or evaluated. These have included using the FCI as an evaluative instrument (either in its entirety [18,19,30–32] or using selected dimensions of function [17,33–36]); as a discriminative tool to identify a study cohort predicted to have functional loss [18,37]; and as part of a number of approaches to generate estimates of lifetime morbidity in an injured population [24,29,38–41]. A detailed discussion of these uses is beyond the scope of this review, although it is relevant to note that the evaluative FCI has been used in studies validating the pFCI [17–19].

Validation, strengths and limitations of the original FCI

The original pFCI performed poorly in validation studies [17–19]. In one study, moderate correlations were found between the pFCI and other outcome assessments, although it was suggested that the FCI better discriminated between head-injured patients of differing AIS severity [18]. However, not all of the study data were reported, and the proportion of patients without functional loss at 12 months was at least double that predicted by the pFCI [18]. In a group of patients with lower extremity injury, the predictive FCI demonstrated poor agreement with assessed and self-reported outcomes, and over-predicted good functional recovery [17]. In the most recent validation of the original pFCI, Schluter et al. found poor agreement between predicted and observed FCI scores, with a weighted kappa value of only 0.05 [19]. This poor validity and an overall lack of evaluation of the pFCI have been commented on in a number of reviews [11,42–45].

The novel, multistage approach used in the FCI's development, comprising a mixture of preference-based and expert panel measurements has been highlighted as both a limitation [43,46] and a strength [47,48] of the instrument. It has been asserted that predictive tools “represent a professionals' view of the problem rather than the patient's” [43] – although it may equally be observed that expertise in patient assessment does not necessarily translate to expertise in outcome prediction. On the other hand, it has also been suggested that because of ‘hedonic adaptation’ (where injury sufferers will report similar life satisfaction to pre-injury after a period of adjustment), an expert assessment of function is useful [47,48]. Considerable variability in rating the impact of functional loss was also seen both between and within different groups of raters used during the FCI's development [14,49]. Also, the dimensions used in the FCI have been questioned, as dimensions such as emotional and psychosocial outcomes [36,45] and pain [50] are not considered.

The underlying assumption that the overall disability is equivalent to that of the single worst injury sustained has been questioned. Schluter et al. assessed the effects of injuries to different body regions, and found that the pFCI for head injuries and multiply-injured patients with lower extremity fractures under-predicted the observed functional loss [19]. The additional effects of multiple injuries have been noted elsewhere [51]. However, the problem of how best to consider overall functional loss in the presence of multiple disabling injuries has not been further evaluated using the pFCI.

A number of authors have also observed variability in the predictive ability of the pFCI, particularly across levels of injury severity. In addition to the variations between body regions noted by Schluter et al. [19], Kuppa et al. also commented that the functional loss associated with some lower extremity injuries to the foot and ankle appeared to be under-estimated by the FCI, but contrasted this by noting that the FCI appeared to over-estimate the severity of femoral shaft fractures [52]. Under-estimation of the functional loss resulting from minor injury has also been observed in cervical spine injuries. Using insurance data from Sweden, Gustafsson et al. found that 63% of injured patients with long-term impairment (defined as impairment still present 3 years post injury) had impairment resulting from ‘whiplash’-type injuries to the cervical spine [53]. In another study using the same data source, minor injuries to the cervical spine carried only a 3% likelihood of causing functional loss at 3 years, but accounted for the majority of patients with impairment [54]. These injuries, which are under-represented in hospital admissions data [55], have only a level 1 severity using AIS, and are not predicted to have functional loss at 12 months using the pFCI [15]. Variability in outcome prediction between more and less severe injury is not unique to the pFCI [56], but remains an important limitation of this and other panel-derived tools. The considerable population morbidity arising from minor trauma has also been noted elsewhere [57,58].

Development of the revised FCI

The development, initial testing and preliminary validation of the original pFCI was sponsored and partly conducted by the U.S.

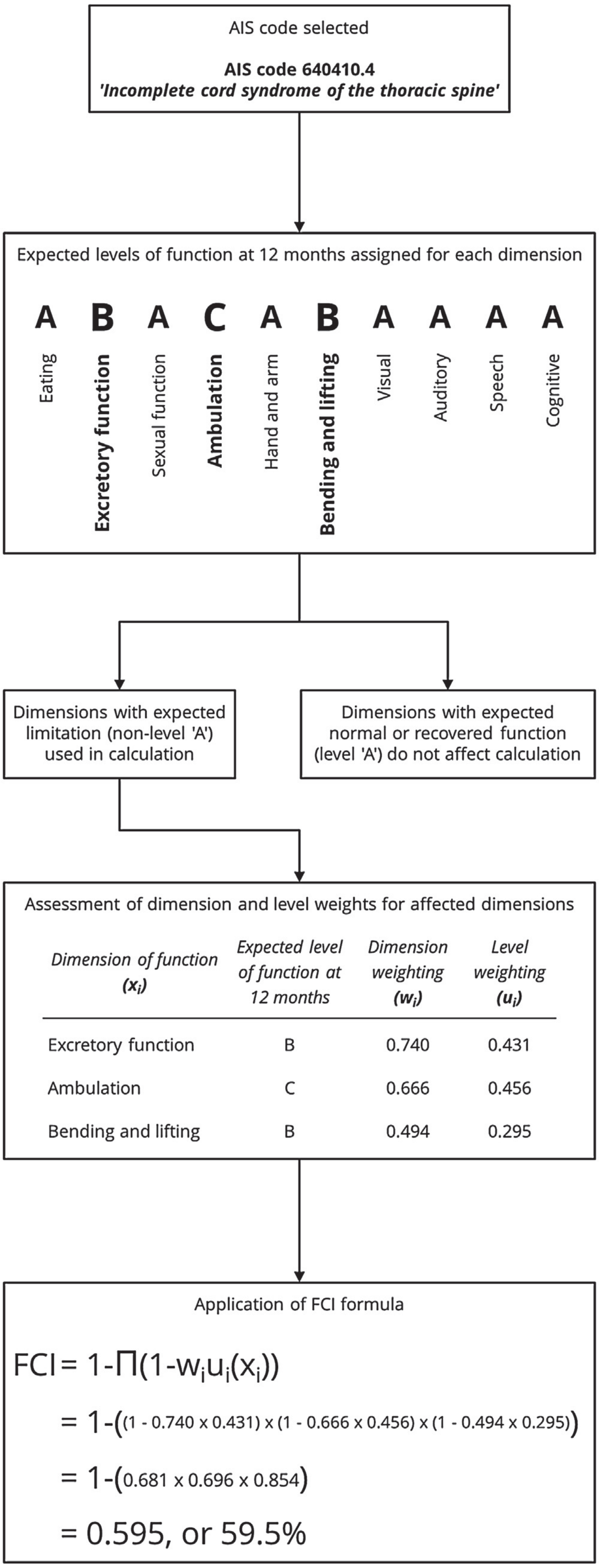

Fig. 1. Calculation of pFCI for a single AIS code. Level weights taken from MacKenzie et al. [13] are applied to the formula in MacKenzie et al. [14] to derive the FCI value provided by Segui-Gomez [15].

National Highway Traffic Safety Administration [13–15,29,30,49]. Ten years later, the same organisation sponsored the development and dissemination of the revised pFCI [20,59,60], although much of the maintenance of the revised FCI and the derived pFCI08 were undertaken by the European Center for Injury Prevention (ECIP) at the University of Navarra in Pamplona, Spain [4]. Through ECIP, files containing more detailed descriptions of the FCI calculation for each 2008 AIS code (specifically, the level of function expected in each dimension 12 months after a given injury) could be obtained [4,27], in the same manner as the detailed descriptions available for the original FCI [15]. However, at the time of writing this manuscript the ECIP web links published in the 2008 AIS dictionary [4] and other sources [27] were no longer valid. As such, it is publicly unclear which organisation or organisations are wholly or jointly responsible for the maintenance and future development of the FCI.

Structure of the revised pFCI

Table 3 illustrates the changes made to the structure of the FCI between the two versions of the instrument. Although the 10 dimensions of function used in the FCI remain unchanged between the versions, most of the numerical data underlying this – the number of levels of function in each dimension; the weighting between these levels; the overall weighting of each dimension in calculating the FCI; and the formula used to summarise the scores – have changed. However, the exact dimension and level weights used in the revised pFCI remain unknown, as at the time of writing this manuscript they have not been published, and the formula for calculation of revised pFCI scores pre-combines dimension and level weights [21]. In the absence of available detailed information regarding the revised pFCI, only the five-level pFCI08 contained in the 2008 AIS dictionary is publicly available.

Although the revised FCI was developed in 2005, much of the information known about this version was not published until a decade later in late 2015 (Table 3) [21]. This lack of information about the construction of a widely-available instrument was first noted by Barnes and Morris in 2009 [16]. In particular, they commented on the lack of a description for pFCI08 levels 2 to 4 (i.e., some level of impairment, but not maximal impairment) [16]. Also, in assuming that the same 'expert panel' approach used in the development of the original FCI had been retained, Barnes and Morris [16] questioned how the approach might have been used in the development of the pFCI08 [16]. A recent publication reported that this approach was discarded in the revised FCI in favour of the more commonly used standard gamble technique [21].

Validation of the revised FCI

For several years, a brief 2005 paper provided the only preliminary 'validation' of the revised FCI [20]. This paper provided a brief overview of the substantial changes made in the development of the 2005 revision of the AIS, and noted that the FCI had been revised concurrently [20]. Also contained was a brief descriptive comparison of the pFCI scores (for both FCI versions) for eight patients with lower extremity fractures whose levels of function were assessed 12 months following injury. It was asserted that pFCI scores for the revised FCI were more closely associated with the measured outcomes than the original pFCI scores [20], although both were poorly correlated with different sub-scores of the generalised Short Form 36 (SF-36) [37,43]. Also, as there were inconsistencies between the revised pFCI scores for the injuries given in this paper [20] and the summarised pFCI08 severities in the 2008 AIS dictionary [4], it may be that this preliminary analysis [20] was performed using an early, unpublished version of the

Table 3
Comparison between structure of original and revised versions of the FCI.

	Functional Capacity Index (1994, 1996) [13,14]	Revised Functional Capacity Index (2005, 2008) [4,20]
AIS version used for predictive FCI	1990 [15]	2008 update [4]
Method of disability assessment	Combination of preference-based and expert panel [13,14]	Standard gamble technique [21]
Number of health states per FCI dimension	48 states in total [14,15]	40 states in total [79]
– eating	3	3
– excretory function	4	3
– sexual function	3	3
– ambulation	6	5
– hand & arm function	6	5
– bending and lifting	4	4
– visual function	7	4
– auditory function	5	3
– speech	4	4
– cognitive function	6	6
Formula used to calculate FCI scores	$FCI = 1 - \prod_{i=1}^{10}(1 - w_i u_i(x_i))$	$FCI = 40 \times \prod_{d=1}^{10}\left(\frac{FCI_d - 60}{40}\right) + 60$
Range of pFCI scores obtained	0 (no limitation) to 100 (worst), expressed as percentage [21]	60 (worst) to 100 (no limitation) [21]
Range of summary scores used in AIS-based pFCI	1 (minor limitation) to 5 (worst); no limitation not included [15]	1 (worst) to 5 (no limitation) [4]
Method for deriving summary scores	AIS injuries with expected limitation divided into 20% bands of percentage functional loss [15]	AIS injuries with expected limitation fairly evenly divided between scores 1–4 [21]
AIS codes with expected limitation in pFCI	321 of 1312 (24.5%) [15]	619 of 1999 (31.0%) [4]
AIS codes excluded from pFCI evaluation	40 of 1312 (3.0%) [15]	103 of 1999 (5.2%) [4]
Type of AIS codes excluded from pFCI evaluation	Skin injuries (including burns), with some exceptions [15]	Mostly 'whole region (NFS)' injuries, burn injuries and 'other trauma' section of AIS External chapter [4]

2005 AIS, which was not definitively standardised until the publication of the 2008 AIS dictionary [61].

A 2016 paper by McMurry et al. sought to validate the revised pFCI against patient-reported physical component scores (PCS) using the SF-36 [62]. Three methods were used – an assessment of correlation between the revised pFCI and SF-36 PCS; the fitting of a regression model predicting SF-36 PCS including the pFCI; and a review of outliers (patients for whom the pFCI under- or over-predicted outcome) [62]. However, there were several limitations with the methods used. Firstly, more than 90% of the AIS-coded data used was migrated from the 1998 to the 2008 AIS versions based solely on the incomplete map contained in the 2008 AIS dictionary [62]; it has been identified that using this method results in inaccurate summary scores in a substantial proportion of patients [63]. Secondly, an unvalidated method of combining pFCI scores in patients with multiple disabling injuries was used [62]. Thirdly, although a weak correlation of 0.24 (using unstated methods) was found between the 40-point pFCI and the 100-point PCS [62], the linearity of this association was not evaluated (or at least was unreported). As the pFCI (ranging between 60 and 100) and the PCS (ranging between 0 and 100) are also measured using different scales, correlation is unlikely to be informative in linking predictive pFCI scores with assessed outcomes. Fourthly, although the revised pFCI was identified as a significant predictor of outcome using a regression model, it was just one of 18 predictors in the model which were significant at a 95% confidence level [62]. As a result, this paper did not provide sufficient evidence to validate the revised pFCI in predicting functional outcomes.

Use of the revised FCI

To date, only five papers have used the revised FCI [16,21,64–66]. Barnes and Morris used a crash dataset to compare the functional loss predictions from the pFCI08 (based on the 2008 AIS) with those from the earlier Injury Impairment Scale (IIS, based on 1990 AIS codes) [16]. Because the study did not assess actual outcomes following injury, the predictive performances of the two tools could not be compared. The primary findings were that the proportion of patients expected to have functional loss at 12 months was lower for the pFCI08 than for the IIS, and that in the population evaluated there were differences in the body regions predicted to contribute most to population morbidity [16]. The authors speculated that in part this may have been due to changes in the coding of head and lower extremity injuries between the 1990 and 2008 versions of the AIS [16].

Poplin et al. used the pFCI08 to predict functional loss in a cohort of fire department employees who sustained occupational injury [66]. In their population, 18% of injured employees were predicted to have functional loss as a result of the injuries they sustained [66]. However, the majority of injuries sustained which required time off work were minor sprains and strains for which the pFCI does not predict functional loss [66]. It was conceded that short-term loss of function was unlikely to be accurately measured by the 12-month pFCI08 [66].

In two separate papers, Breeze and colleagues used computer modelling (based on injury data from a military trauma registry) to predict changes in the pFCI08 and 2008 AIS ratings of injury severity which would result from the introduction of, or modifications to a range of facial armour configurations [64,65]. The AIS and pFCI08 were not significantly different from clinical findings in the same patients (based on mean pFCI08) [65], and worse outcomes on both AIS and pFCI08 were demonstrable for patients not wearing ballistic eye protection [64]. However, because of the method used for evaluating pFCI08, and the study focus on the protection worn, no validation between the observed and predicted pFCI08 scores was obtained.

In 2015, McMurry et al. used crash study data to assess predicted years of life lost to injury and associated costs for a 14-year cohort of patients [21]. The majority of patients were coded using earlier versions of the AIS, and a novel mapping technique was used to convert these AIS codes to 2008 AIS equivalents (and hence derive pFCI08 values) [21]. This methodology was able to calculate estimates of population morbidity and costs using pFCI08 data. However, the accuracy of these estimates was not assessed against any other measures of morbidity or cost.

Assessment of the extent to which earlier FCI limitations have been overcome

Generally, the limitations of the original FCI have not been addressed by the revised FCI. Barnes and Morris noted that pain was a “major factor” affecting function [16]; however this could not be assessed using either the original or the revised FCI as the dimensions of function covered by the instrument did not change. Both Barnes and Morris, and Poplin et al. also identified ‘neck strain' injury – which the pFCI08 predicts is unlikely to result in functional loss at 12 months – as a cause of significant impairment in many patients [16,66]; the former paper also commented that the pFCI08 continues to under-estimate functional loss from lower extremity injury [16].Some of these findings were corroborated by McMurry et al. [62], who found that spinal fractures expected to fully recover according to the revised pFCI made up the majority of ‘unexpected' functional loss at 12 months post-injury [62]. However, the same study also found that lower limb fractures for which the pFCI predicted functional loss occurred in the majority of patients with an ‘unexpected' full recovery as assessed using the SF-36 PCS [62]. This suggests that not all lower extremity injuries are under-estimated by the revised pFCI. From the data presented, though, it appears likely that the pFCI08 scores for some comparatively minor injuries continue to over-predict functional recovery. Barnes and Morris also criticised the tendency of the pFCI08 to vary in the prediction of head injury outcomes only between no impairment and maximal impairment, with few injuries predicted to result in moderate levels of impairment [16]. McMurry et al. found that the revised pFCI also varied in its ability to predict outcomes from head injury, with full recovery being assessed in some patients with poor pFCI predictions, but substantial functional loss occurring in some patients who were expected to fully recover according to the pFCI [62].

There remains little agreement about the best method for accounting for the presence of multiple injuries in a single patient – particularly multiple injuries with a pFCI08 predicting functional loss. McMurry et al. re-iterated the ‘worst injury' technique that was advocated for the original pFCI, as well as suggesting an alternate technique referred to as ‘whole body FCI' which involved combining the worst injuries in each dimension of function and combining them into a new, patient-specific FCI [21]. This technique was re-used in the later validation study by McMurry et al. [62]. It requires information on specific dimension and level weights, similar to the formula for original pFCI scores and unlike the formula stated to calculate pFCI08 scores (Table 3). However, although these weights for the revised FCI were available to McMurry and colleagues [21,62] they are not currently publicly available and the validity (or superiority) of this method cannot be broadly assessed.

Finally, the four assumptions which governed the assignment of codes in the original pFCI [13,14] remain for the pFCI08 [21] – namely, that the levels of functional loss predicted by the pFCI to be present at 12 months assume that the patient is young, previously healthy, received good medical care and sustained a single disabling injury. The section of the 2008 AIS dictionary that discussed the FCI confirmed the assumptions with the exception that FCI assignment was “for a subject aged 18–65” [4]. As this is the only instance where this different age group is stated, it is possible that this was misprinted. However, it should be noted that the selection of the 18–34 year age group has never been validated, and may itself be arbitrary.

The future: FCI2015 and directions for research

Although it has been more than a decade since the revised FCI was developed, and eight years since the publication of the pFCI08 in the widely-adopted 2008 AIS [4], evidence for the validity of this instrument is lacking. Few studies have used the pFCI08, and although these have demonstrated that the pFCI08 could potentially be used in a number of ways none have been able to fully gauge the accuracy of outcome predictions made by the pFCI08. With a new AIS version due [67], it is important that the pFCI08 be further validated to adequately assess its potential to add a morbidity prediction to the mortality-biased severity estimates provided by AIS scores.

Future validation could consider whether the pFCI is valid in the population for which it was intended [13,14,21] – namely, young and previously healthy patients who have sustained isolated injury – as well as testing these assumptions by assessing the pFCI in a broader population. Furthermore, because many severely injured patients sustain multiple injuries, data about how best to use the pFCI08 when multiple injuries are present is needed. Related to this is the need to ensure that (or evaluate whether) the pFCI08 performs equally across different body regions. The technique employed by McMurry and colleagues [21,62] to calculate ‘whole body' pFCI08 scores for each patient also warrants further consideration, but would require more detailed data on dimension and level weights for the revised FCI to be made publicly available. At present, only the truncated scores available in the 2008 AIS dictionary are widely accessible.

Anatomical injury severity scores have been found to explain only a small proportion of the variability in observed trauma outcomes [19,26]. Conversely, many other factors have been found to independently predict outcomes 12 months or more post injury. These include:

- pre-injury factors such as education level [48,68], age [57,68–73], gender [57,73,74] and comorbid status [48,57,71,73];
- injury event factors such as the intent [71,73] and mechanism [71,73] of injury, the Injury Severity Score [70,72], or the presence of serious injury to the extremities [48,57,70–72,75], brain [48,70,71] or spinal cord [48,57,71,73];
- hospital-related factors such as the level of hospital providing definitive care [70], length of ICU stay [68,75], length of hospital stay [68,72], the discharge destination [70] or the occurrence of complications [76]; and
- post-discharge factors such as pain levels [68], compensability [68,70,71,73], and the presence of depression or PTSD [75].

The extent to which some of these factors affect outcomes has varied between studies, or their effects have been found to be limited to particular aspects of function. In addition, it is likely that many of the models evaluated for outcome prediction have not included all potential explanatory factors. Nevertheless, predictions based solely on anatomic injury (as the pFCI attempts to achieve) are unlikely to be sufficiently accurate for prognostic use. However, the component of long-term functional loss attributable to the anatomical injuries sustained should be identified [30]. Only then can further progress be made towards a better, more inclusive prognostic model for predicting functional outcome after severe injury.

Limitations

It is possible that other research not discussed in this review has evaluated the pFCI. This review was not designed as a systematic review per se, but used a broad search strategy employing a variety of complementary databases with coverage of non-English journals and 'grey literature' [77,78]. This is exemplified by the identification of conference posters, and published abstracts and conference proceedings by the search [27,30,50,52,64]. Also, many of the papers identified by the search strategy were themselves reviews on injury outcomes, or functional or quality of life assessment; this provided additional opportunity to identify studies of interest although no additional studies were identified.

Conclusion

The revised pFCI offers the potential to predict functional outcomes using existing AIS codes. However, it is not well-validated, not readily accessible and does not have an agreed methodology for its use, particularly when multiple injuries are present. The truncated pFCI08 is widely-available, and hence could potentially facilitate predictions of the morbidity burden arising from injury using current AIS scoring. This would be able to address ongoing calls for the assessment of morbidity in trauma populations [12]. However, the pFCI08 is currently not validated. A number of identified issues with pFCI08 scores, including the variability in predictive ability across anatomical regions and severity levels, and methods for accounting for multiple injuries also require assessment. These issues pose a barrier to the ideal of low-cost and reliable assessment of likely functional outcomes across an injured population, including the development of more comprehensive predictive tools.

Conflict of interest

We declare that there are no external funding sources related to this study, and that there are no conflicts of interest related to this study.

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4.3 SUMMARY

The FCI was developed with the intent of using existing AIS-coded data in a way which provides for the routine prediction of functional outcomes. The current version of the FCI was developed in parallel with the 2005 (and later the 2008) AIS, and exists in two forms. The first form of the FCI is more detailed and provides separate, weighted predictions of function across ten different dimensions of function; its primary limitation is a lack of general availability. The second form is widely available within the 2008 AIS dictionary, but has been heavily truncated to a five-point scale.

There are several known or potential limitations to the FCI. One is the observed inconsistencies in the accuracy of the FCI's predictions between different body regions, and even between similar injuries; a second is the lack of an agreed method for summarising the FCI's predictions where multiple injuries exist. An important limitation of the FCI surrounds the assumptions made by the its developers regarding the outcome predictions it makes - specifically, that the FCI is designed for predicting outcomes in young, previously healthy patients who sustain single injuries and receive proper care for these injuries.[15,157,165]

The detailed form of the revised (2008) FCI has not been well-validated, and the truncated form has not been validated at all. As such, although the potential for this tool is substantial, its practical usefulness has yet to be established. Outcomes amongst the survivors of severe trauma vary widely, and anatomical injury may only represent a small proportion of this variability. Consequently, methods for summarising injuries in a way which aim to reflect the likely functional recovery or loss following trauma should be evaluated so as to be as accurate as possible.

Given the potential of the FCI, validation of its predictive ability is essential. However, as the FCI was designed with inherent assumptions in mind, a logical first step is to evaluate the performance of the FCI within the narrow population group used by its designers.

Chapter Five
Preliminary Assessment of the FCI

5.1 Overview of Chapter

The review conducted in Chapter Four demonstrated that the widely-available FCI contained within the 2008 AIS dictionary has not been validated. As such, although potentially providing a useful tool for predicting functional outcomes following trauma the practical usefulness of FCI remains unknown.

The paper presented in this chapter applies both the 2008 AIS and the associated truncated FCI score to a population of major trauma patients, to assess how well the FCI is able to predict 12-month functional outcomes (as measured using structured telephone interviews) in patients with single injuries. At the same time, the performance of the FCI was compared to the mortality-weighted AIS on which its structure is based. The developers of the FCI derived its severities based on four restrictive assumptions; consequently, sensitivity analyses about the need for one of these assumptions were also undertaken.

The following paper, 'Revised Functional Capacity Index as a predictor of outcome following injury' was accepted for publication by the British Journal of Surgery in May 2017, and published in print in December 2017. It is currently available online via the following link:

https://onlinelibrary.wiley.com/doi/abs/10.1002/bjs.10638.

A supplementary table (Table S1 - supporting information) was included with this paper, and has been reproduced in this thesis in Appendix Three.

5.2 Published Paper

Revised Functional Capacity Index as a predictor of outcome following injury

Declaration for Thesis Chapter Five

Palmer CS, Gabbe BJ, Cameron PA. Revised Functional Capacity Index as a predictor of outcome following injury. Br J Surg 2017 Dec; 104(13):1874-1883. doi: 10.1002/bjs.10638

In the case of Chapter Five, the nature and extent of my contribution to the work was the following:

Nature of contribution	**Extent of contribution (%)**
Study conception and design; statistical testing; development of tables and figures; manuscript drafting and revision	70%

The following co-authors contributed to the work. There are no student co-authors.

Name	**Nature of contribution**
Belinda Gabbe	Conception and design of study, and manuscript revision
Peter Cameron	Conception and design of study, and manuscript revision

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the candidate's and co-authors' contributions to this work.

Candidate's signature	[redacted]	Date: 1 July 2019
Main supervisor's signature	[redacted]	Date: 1 July 2019

Revised Functional Capacity Index as a predictor of outcome following injury

C. S. Palmer[1,2], B. J. Gabbe[1,3] and P. A. Cameron[1,4]

[1]Department of Epidemiology and Preventive Medicine, Monash University, and [2]Trauma Service, Royal Children's Hospital Melbourne, Melbourne, Victoria, Australia, [3]Farr Institute – Centre for Improving Population Health through E-Health Research (CIPHER), College of Medicine, Swansea University, Swansea, UK, and [4]Emergency Medicine, Hamad Medical Corporation, Doha, Qatar

Correspondence to: Mr C. S. Palmer, Trauma Service, Royal Children's Hospital Melbourne, Flemington Road, Parkville, Victoria 3052, Australia (e-mail: cameron.palmer@rch.org.au)

Background: Assessment of functional outcomes in survivors of severe injury is an identified priority for trauma systems. The predictive Functional Capacity Index (pFCI) within the 2008 Abbreviated Injury Scale dictionary (pFCI08) offers a widely available tool for predicting functional outcomes without requiring long-term follow-up. This study aimed to assess the 12-month functional outcome predictions of pFCI08 in a major trauma population, and to test the assumptions made by its developers to ensure population homogeneity.

Methods: Patients with major trauma from Victoria, Australia, were followed up using routine telephone interviews. Assessment of survivors 12 months after injury included the Glasgow Outcome Scale – Extended (GOS-E). κ scores were used to measure agreement between pFCI08 and assessed GOS-E scores.

Results: Of 20 098 patients with severe injury, 12 417 had both pFCI08 and GOS-E scoring available at 12 months. The quadratic weighted κ score across this population was 0·170; this increased to 0·244 in the subgroup of 1939 patients who met all pFCI assumptions. However, expanding the age range used in this group did not significantly affect κ scores until patients over the age of 70 years were included.

Discussion: The pFCI08 has only a slight agreement with outcomes following major trauma. However, the age limits in the pFCI development assumptions are unnecessarily restrictive. The pFCI08 may be able to contribute to future systems predicting functional outcomes following severe injury, but is likely to explain only a small proportion of the variability in patient outcomes.

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Introduction

In high-income countries, the vast majority of severely injured patients survive their injuries. The introduction of trauma systems has led to reductions in mortality following severe injury, although substantial post-traumatic morbidity remains amongst survivors[1,2]. Measurement of functional and quality-of-life outcomes has been widely identified as a priority for trauma systems[2–6], although few have successfully implemented routine follow-up of severely injured patients[5,6]. The predictive version of the Functional Capacity Index (pFCI)[7–9] is a multiattribute tool designed to predict functional outcomes for single injuries 12 months after trauma. A truncated version of this instrument is included in the most recent (2008) version of the Abbreviated Injury Scale (AIS) dictionary (AIS08)[10]. This version of the pFCI (termed pFCI08) provides an alternative measure to AIS severity estimates, which are known to be biased towards mortality risk[11,12]. Thus, the pFCI08 offers a widely available tool with the potential to estimate functional outcomes across trauma populations – either in isolation or within a more inclusive model – without the need for long-term follow-up.

However, the original version of the pFCI performed poorly in predicting functional outcome following injury[13]. Although the pFCI08 was designed to address weaknesses in the pFCI[14], a recent review[15] showed that this version of the tool has not been validated adequately, and has been used in only a few studies[16–20]. As a result, the utility of functional outcome predictions made using the pFCI08 remains unknown.

The present study aimed to assess whether the pFCI08 contained within the AIS08 dictionary was capable of predicting 12-month functional outcomes across a major trauma population, and whether pFCI08 predictions were superior to those offered by AIS08 severities. A secondary aim was to assess whether the arbitrary assumptions, particularly that relating to age, inherent in the design of the pFCI08[7,8,17] were necessary for population homogeneity in a group of otherwise healthy patients with isolated injury.

Methods

Setting and study participants

Established in July 2001, the Victorian State Trauma Registry (VSTR) collects data on hospitalized patients with major trauma managed in the Australian state of Victoria. Victoria contains almost six million people in an area approximately the same size as the UK. Data are collected from all hospitals in the state that receive injured patients, and consent for inclusion on the registry is through an opt-out approach[3]. Complete inclusion and exclusion criteria for the VSTR have been published elsewhere[21].

Major trauma is defined within Victoria as not only patients who die or sustain injuries with a high Injury Severity Score (ISS; using a threshold greater than 12 since adopting AIS08)[22], but also those who require urgent surgical management or spend more than 24 h in an ICU (and require mechanical ventilation)[21]. For this study, data for all patients with major trauma captured by the VSTR over the 7·5-year interval from January 2007 to June 2014 were obtained.

Ethical approval for the study was provided by the Monash University Human Research Ethics Committee.

Procedures

Since October 2006, the VSTR has collected 12-month follow-up data via telephone interview for all severely injured adults who survived to hospital discharge[23]. During follow-up interviews with patients or carers, a suite of measures is administered to collect function, health-related quality of life, return to work, residential status and pain scores[3]. The primary measure of functional outcome administered is the extended Glasgow Outcome Scale (GOS-E)[3,24]. This tool, which has been validated in trauma populations[24], provides a global assessment of function on an eight-point scale ranging from death to ‘upper good’ recovery across a range of domains reflecting daily functions[3,23].

As well as AIS08-coded injury data and 12-month functional outcome assessments, data on age, sex, injury mechanism and compensability status was obtained. Patients with major trauma who were injured before July 2010 were originally coded using the 1998 version of the AIS; these codes were mapped to AIS08 equivalents using validated mapping tools[25,26]. Patients aged less than 18 years at the time of injury were excluded from the analysis. AIS08 injury data were used to extrapolate pFCI08 scores. The worst pFCI08 score for each patient was then established, as this has been advocated by the developers of the pFCI as a suitable method for characterizing overall functional loss[8,9]. Patients who sustained only one injury with a pFCI08 score below 5 (that is, a single disabling injury) were also identified.

Data analysis

Agreement between predictive (pFCI08 or AIS08) and assessed GOS-E scores was evaluated in three successively narrowing populations: all surviving adults with valid pFCI08 scores; patients meeting pFCI assumptions relating to single injury and co-morbidity; and patients additionally meeting pFCI assumptions relating to age. Assessment of the assumption relating to appropriate and timely care was beyond the scope of this study. Because the Victorian State Trauma System is well established in a high-income country, good care was likely to have been received by many patients in the population. However, assessing the quality of care provided at patient level was beyond the scope of the present study.

Agreement between predictive and assessed scores was evaluated using both unweighted and quadratic weighted values of κ, as the latter is equivalent to the intraclass correlation coefficient for these ordinal data measures[27]. Weighted methods of analysis were useful as a substantial number of patients were expected to have outcomes that varied from those predicted by the pFCI08. Confidence intervals for κ were calculated using a bootstrap method with 1000 replications, as this returned symmetrical confidence intervals. Owing to large sample sizes, differences between calculated κ values (with confidence intervals) were constructed using the normal distribution with pooled errors. Rating of κ values was performed using descriptions published by Byrt[28].

Sensitivity analyses

The seven GOS-E categories corresponding to patient survival were collapsed into a five-point scale for κ analysis to

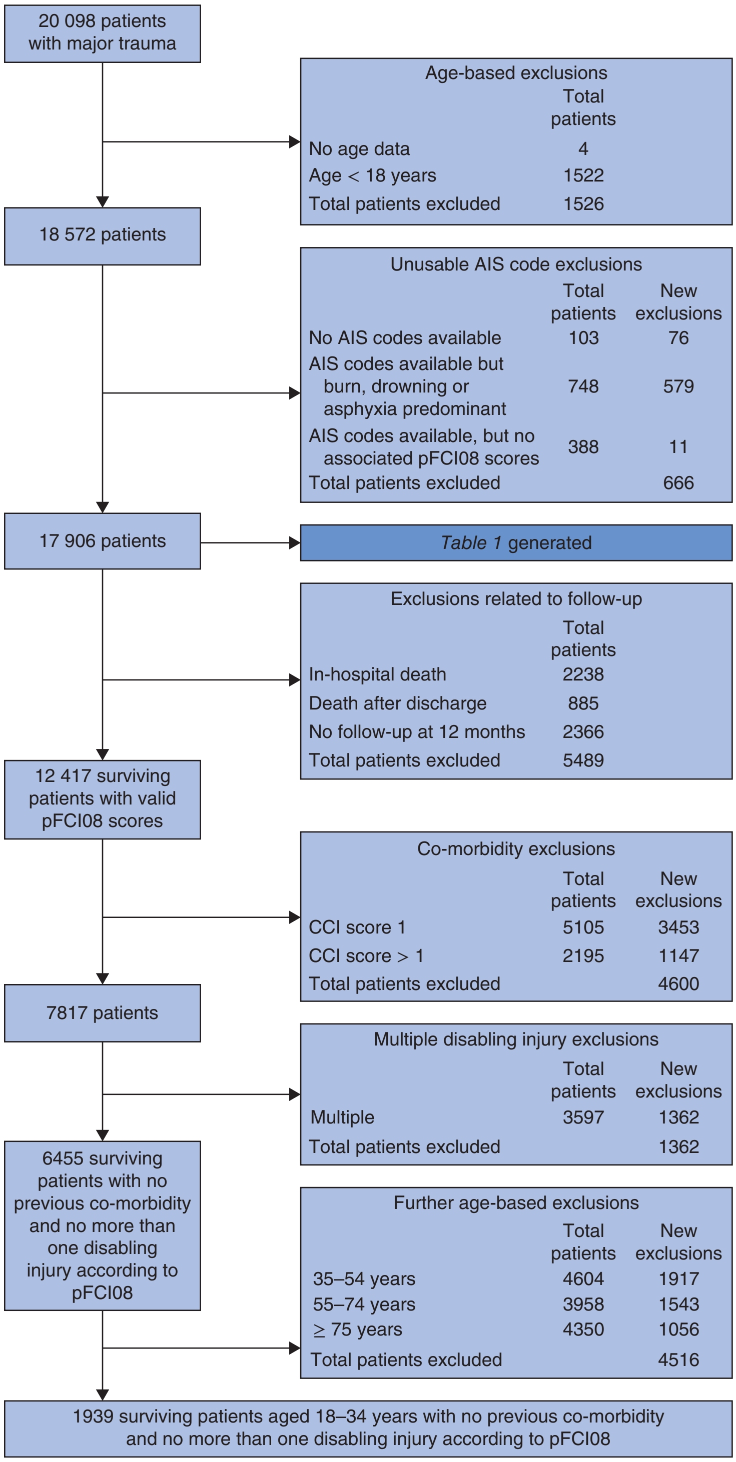

Fig. 1 Flow diagram showing derivation of the data set for assessing the performance of the predictive Functional Capacity Index within the 2008 Abbreviated Injury Scale (AIS) dictionary (pFCI08), using 20 098 patients with major trauma captured by the Victorian State Trauma Registry. CCI, Charlson Co-morbidity Index

Table 1 Demographics and injury severity for adults with major trauma and valid pFCI08 data, including subsets of patients used for evaluation of agreement between pFCI08 and GOS-E

	Age group (years)					pFCI08 evaluation	
	18–34 (*n* = 4994)	35–54 (*n* = 4604)	55–74 (*n* = 3958)	≥ 75 (*n* = 4350)	Total (*n* = 17 906)	No co-morbidity and single injury (*n* = 6455)	No co-morbidity, single injury and aged 18–34 years (*n* = 1939)
Sex							
M	4003 (80·2)	3647 (79·2)	2876 (72·7)	2141 (49·2)	12 667 (70·7)	4649 (72·0)	1546 (79·7)
F	991 (19·8)	957 (20·8)	1082 (27·3)	2209 (50·8)	5239 (29·3)	1806 (28·0)	393 (20·3)
Mechanism of injury							
Occupant in motor vehicle collision	1743 (34·9)	1064 (23·1)	755 (19·1)	479 (11·0)	4041 (22·6)	1465 (22·7)	629 (32·4)
Other transport-related	1296 (26·0)	1445 (31·4)	776 (19·6)	307 (7·1)	3824 (21·4)	1594 (24·7)	496 (25·6)
Fall ≤ 1 m	228 (4·6)	449 (9·8)	1179 (29·8)	3201 (73·6)	5057 (28·2)	1268 (19·6)	94 (4·8)
Fall > 1 m	394 (7·9)	570 (12·4)	766 (19·4)	241 (5·5)	1971 (11·0)	826 (12·8)	128 (6·6)
Piercing, cutting or gunshot	397 (7·9)	267 (5·8)	67 (1·7)	22 (0·5)	753 (4·2)	313 (4·8)	173 (8·9)
Other	936 (18·7)	809 (17·6)	415 (10·5)	100 (2·3)	2260 (12·6)	989 (15·3)	419 (21·6)
Intent of injury							
Unintentional	3897 (78·0)	3816 (82·9)	3725 (94·1)	4272 (98·2)	15 710 (87·7)	5755 (89·2)	1568 (80·9)
Intentional (assault or self-harm)	1004 (20·1)	687 (14·9)	191 (4·8)	41 (0·9)	1923 (10·7)	625 (9·7)	342 (17·6)
Other or unspecified intent	93 (1·9)	101 (2·2)	42 (1·1)	37 (0·9)	273 (1·5)	75 (1·2)	29 (1·5)
Compensability of injuries							
Compensable	2825 (56·6)	2201 (47·8)	1371 (34·6)	715 (16·4)	7112 (39·7)	2608 (40·4)	1018 (52·5)
Non-compensable	2169 (43·4)	2403 (52·2)	2587 (65·4)	3635 (83·6)	10 794 (60·3)	3847 (59·6)	921 (47·5)
Co-morbidity present							
Healthy (CCI = 0)	3359 (67·3)	3043 (66·1)	2314 (58·5)	2328 (53·5)	11 044 (61·7)	6455 (100)	1939 (100)
Co-morbidity (CCI > 0)	1635 (32·7)	1561 (33·9)	1644 (41·5)	2022 (46·5)	6862 (38·3)	–	–
Status at 12 months after injury							
Survived	3730 (74·7)	3614 (78·5)	3005 (75·9)	2068 (47·5)	12 417 (69·3)	6455 (100)	1939 (100)
Died (in hospital or before follow-up)	265 (5·3)	262 (5·7)	573 (14·5)	2023 (46·5)	3123 (17·4)	–	–
Lost to follow-up	999 (20·0)	728 (15·8)	380 (9·6)	259 (6·0)	2366 (13·2)	–	–
ISS group*							
< 13	761 (15·2)	570 (12·4)	505 (12·8)	866 (19·9)	2702 (15·1)	921 (14·3)	353 (18·2)
13–14	992 (19·9)	1186 (25·8)	863 (21·8)	758 (17·4)	3799 (21·2)	1782 (27·6)	468 (24·1)
16–19	1248 (25·0)	1157 (25·1)	1117 (28·2)	1151 (26·5)	4673 (26·1)	2003 (31·0)	537 (27·7)
20–24	622 (12·5)	633 (13·7)	468 (11·8)	318 (7·3)	2041 (11·4)	771 (11·9)	234 (12·1)
25–38	1115 (22·3)	899 (19·5)	901 (22·8)	1200 (27·6)	4115 (23·0)	924 (14·3)	322 (16·6)
> 40	256 (5·1)	159 (3·5)	104 (2·6)	57 (1·3)	576 (3·2)	54 (0·8)	25 (1·3)
Maximum AIS score							
1–2	415 (8·3)	320 (7·0)	247 (6·2)	426 (9·8)	1408 (7·9)	454 (7·0)	178 (9·2)
3	2311 (46·3)	2496 (54·2)	1952 (49·3)	1661 (38·2)	8420 (47·0)	3587 (55·6)	1002 (51·7)
4	1401 (28·1)	1106 (24·0)	1034 (26·1)	1173 (27·0)	4714 (26·3)	1776 (27·5)	545 (28·1)
5–6	867 (17·4)	682 (14·8)	725 (18·3)	1090 (25·1)	3364 (18·8)	638 (9·9)	214 (11·0)
Worst pFCI08 score							
5 (best)	2454 (49·1)	2337 (50·8)	2068 (52·2)	2270 (52·2)	9129 (51·0)	4347 (67·3)	1284 (66·2)
4	573 (11·5)	568 (12·3)	448 (11·3)	499 (11·5)	2088 (11·7)	759 (11·8)	229 (11·8)
3	388 (7·8)	353 (7·7)	279 (7·0)	249 (5·7)	1269 (7·1)	291 (4·5)	84 (4·3)
2	523 (10·5)	523 (11·4)	334 (8·4)	188 (4·3)	1568 (8·8)	357 (5·5)	125 (6·4)
1 (worst)	1056 (21·1)	823 (17·9)	829 (20·9)	1144 (26·3)	3852 (21·5)	701 (10·9)	217 (11·2)
No. of disabling injuries (in pFCI08)							
0	2454 (49·1)	2337 (50·8)	2068 (52·2)	2270 (52·2)	9129 (51·0)	4347 (67·3)	1284 (66·2)
1	1303 (26·1)	1214 (26·4)	1122 (28·3)	1541 (35·4)	5180 (28·9)	2108 (32·7)	655 (33·8)
≥ 2	1237 (24·8)	1053 (22·9)	768 (19·4)	539 (12·4)	3597 (20·1)	–	–
Met other pFCI08 evaluation criteria†							
Yes	1939 (38·8)	1917 (41·6)	1543 (39·0)	1056 (24·3)	6455 (36·0)	6455 (100)	1939 (100)
No	3055 (61·2)	2687 (58·4)	2415 (61·0)	3294 (75·7)	11 451 (64·0)	–	–

Values in parentheses are percentages within each breakdown. *Not all Injury Severity Score (ISS) values (including ISS 15, 39 and 40) are obtainable owing to the mathematical construction of the ISS as a sum of no more than three squares. †Previously healthy patient surviving to 12 months with valid Glasgow Outcome Scale – Extended (GOS-E) recorded and single disabling injury or no predicted disability at 12 months. pFCI08, predictive Functional Capacity Index within the 2008 Abbreviated Injury Scale dictionary; CCI, Charlson Co-morbidity Index; AIS, Abbreviated Injury Scale.

Table 2 Unweighted and weighted κ between pFCI08 and GOS-E, and AIS08 and GOS-E, for different population groupings

		Unweighted κ		Weighted κ	
	No. of patients assessed	κ	Difference between score and maximal agreement	κ	Difference between score and maximal agreement
κ between pFCI08 and GOS-E					
(1) All surviving patients with valid pFCI08 and GOS-E scores	12 417	0·094 (0·085, 0·103)	−0·001 (−0·027, 0·025)	0·170 (0·153, 0·189)	−0·074 (−0·120, −0·028)‡
(2) As (1) above, with no co-morbidity and single disabling injury only	6455	0·069 (0·056, 0·085)	−0·026 (−0·054, 0·002)	0·146 (0·122, 0·172)	−0·098 (−0·148, −0·049)‡
(3) As (2) above and aged 18–34 years*	1939	0·095 (0·066, 0·118)	–	0·244 (0·195, 0·294)	–
Sensitivity analysis about age for patients, as (2) above					
Age group (years)					
18–39	2395	0·088 (0·066, 0·112)	−0·007 (−0·040, 0·026)	0·229 (0·190, 0·274)	−0·016 (−0·073, 0·042)
18–44	2871	0·075 (0·053, 0·095)	−0·020 (−0·051, 0·012)	0·209 (0·170, 0·248)	−0·035 (−0·091, 0·020)
18–49	3361	0·078 (0·060, 0·099)	−0·016 (−0·047, 0·014)	0·206 (0·170, 0·242)	−0·038 (−0·092, 0·016)
18–54	3856	0·074 (0·055, 0·091)	−0·021 (−0·050, 0·009)	0·203 (0·168, 0·242)	−0·042 (−0·095, 0·011)
18–59	4307	0·073 (0·057, 0·090)	−0·021 (−0·051, 0·008)	0·198 (0·165, 0·232)	−0·046 (−0·098, 0·006)
18–64	4709	0·078 (0·062, 0·095)	−0·016 (−0·045, 0·013)	0·201 (0·169, 0·234)	−0·043 (−0·094, 0·008)
18–69	5076	0·078 (0·061, 0·093)	−0·016 (−0·045, 0·012)	0·199 (0·171, 0·232)	−0·046 (−0·096, 0·005)
18–74	5399	0·078 (0·061, 0·094)	−0·017 (−0·046, 0·011)	0·190 (0·157, 0·218)	−0·055 (−0·105, −0·004)‡
18–79	5717	0·073 (0·057, 0·087)	−0·022 (−0·050, 0·006)	0·173 (0·142, 0·201)	−0·072 (−0·121, −0·022)‡
18–84	6087	0·071 (0·058, 0·086)	−0·023 (−0·051, 0·005)	0·165 (0·138, 0·194)	−0·079 (−0·129, −0·030)‡
18–89	6323	0·069 (0·055, 0·085)	−0·025 (−0·053, 0·003)	0·151 (0·123, 0·172)	−0·094 (−0·143, −0·044)‡
κ between AIS08 and GOS-E†					
(1) All surviving patients with valid pFCI08 and GOS-E scores	12 417	0·028 (0·022, 0·035)	−0·066 (−0·091, −0·041)‡	0·085 (0·075, 0·096)	−0·160 (−0·204, −0·116)‡
(2) As (1) above, with no co-morbidity and single disabling injury only	6455	0·021 (0·012, 0·028)	−0·074 (−0·099, −0·049)‡	0·061 (0·048, 0·074)	−0·184 (−0·228, −0·139)‡
(3) As (2) above and aged 18–34 years	1939	0·008 (−0·007, 0·023)	−0·087 (−0·114, −0·059)‡	0·036 (0·017, 0·056)	−0·209 (−0·256, −0·162)‡

Values in parentheses are 95 per cent confidence intervals. *Group of patients with maximal agreement between predictive Functional Capacity Index within the 2008 Abbreviated Injury Scale (pFCI08) and Glasgow Outcome Scale – Extended (GOS-E). †Patient groups chosen to compare with agreement between pFCI08 and GOS-E, rather than all patients with valid 2008 Abbreviated Injury Scale (AIS08) codes. ‡Indicates significant difference between each κ value and the κ with maximal agreement.

correspond with the five-point pFCI08. Sensitivity analyses trialling different methods of collapsing GOS-E categories were performed as there is no agreed method for collapsing these categories; only the method resulting in the highest levels of agreement was reported. Patients with maximum AIS08 scores of 5 or 6 were combined as it was anticipated that there would be few surviving patients sustaining injuries of AIS08 level 6 severity.

Sensitivity analysis testing the pFCI developers' assumption relating to age (between 18 and 34 years) was also performed. Commencing with the group of patients meeting other pFCI assumptions and aged between 18 and 34 years, successive 5-year bands of older patients were added and the agreement between predicted (pFCI08) and assessed (GOS-E) scores was recalculated. Differences in weighted κ values between these population regroupings were evaluated.

Statistical analysis

All statistical analyses were performed using Stata® IC 14.0 (StataCorp, College Station, Texas, USA). $P < 0{\cdot}050$ was taken as indicative of statistical significance. Confidence intervals were calculated for proportions and κ values at the 95 per cent level.

Results

Overview and identification of subset for analysis

Some 20 098 patients with major trauma were captured by VSTR data during the study interval. Only 6455 patients (32·1 per cent of the total study population) met the assumptions relating to co-morbidity and single-injury status made by the pFCI developers[7,8,17] (*Fig. 1*). Some 1939 of these patients (9·6 per cent of the total population and

Table 3 Comparison of worst predicted pFCI08 scores and assessed 12-month GOS-E scores in 1939 adults with major trauma who met all assumptions for pFCI08 evaluation

	Worst predicted pFCI08 score					
	1	2	3	4	5	Total
12-month GOS-E score*						
2 Vegetative state	2 (0·9)	0 (0)	0 (0)	0 (0)	0 (0)	2 (0·1)
3 Lower severe disability	29 (13·4)	8 (6·4)	0 (0)	4 (1·7)	28 (2·2)	69 (3·6)
4 Upper severe disability	21 (9·7)	8 (6·4)	4 (5)	9 (3·9)	28 (2·2)	70 (3·6)
5 Lower moderate disability	50 (23·0)	27 (21·6)	20 (24)	49 (21·4)	192 (15·0)	338 (17·4)
6 Upper moderate disability	46 (21·2)	41 (32·8)	24 (29)	67 (29·3)	328 (25·5)	506 (26·1)
7 Lower good recovery	21 (9·7)	18 (14·4)	17 (20)	39 (17·0)	220 (17·1)	315 (16·2)
8 Upper good recovery	48 (22·1)	23 (18·4)	19 (23)	61 (26·6)	488 (38·0)	639 (33·0)
Total no. of patients	217	125	84	229	1284	1939

Values in parentheses are percentages. *A Glasgow Outcome Scale – Extended (GOS-E) score of 1 is equivalent to death and was excluded from the analysis. pFCI08, predictive Functional Capacity Index within the 2008 Abbreviated Injury Scale.

15·6 per cent of the 12 417 patients who survived and were followed up at 12 months) were aged 18–34 years and also met the age-related assumption. Loss to follow-up was low, with 86·8 per cent of patients (15 540 of 17 906) with valid pFCI data having a known outcome at 12 months.

Of the 17 906 patients, 70·7 per cent were men and 43·9 per cent had a transport-related mechanism of injury (*Table 1*). The incidence of stabbing and gunshot injury was low; there were 96 gunshot injuries in total (0·5 per cent of patients), and only 24 amongst the subset of 1939 patients who met all pFCI assumptions (1·2 per cent of this group).

Compared with the rest of the population, the subset of 6455 patients who met pFCI assumptions for co-morbidity and single-injury status had similar patterns of sex distribution, mechanism of injury and compensability. However, the narrower subset of 1939 patients meeting all pFCI assumptions had a higher proportion of men, transport-related mechanisms of injury (particularly as an occupant of a motor vehicle collision) and (as a result) injuries that were compensable. They also had a higher incidence of intentionally inflicted injury (self-harm or assault) and (as a result) injuries arising from cutting, piercing or gunshot. However, the sex and mechanism patterns seen in the narrower subset of 1939 patients did not differ substantially from those in the age group of 18–34 years as a whole. Both subsets (meeting some or all pFCI assumptions) had a higher incidence of injury giving a lower ISS (below 16) and a lower incidence of high ISS (score 25 or above) compared with the study population as a whole.

Performance of pFCI08 in predicting outcome

Calculated κ values were highest when pairs of extreme GOS-E categories were collapsed (GOS-E 2 and 3, and 7 and 8); this method was consequently used throughout. Complete results of the sensitivity analysis performed about methods of collapsing GOS-E categories are provided in *Table S1* (supporting information).

Across the entire population of patients with valid pFCI08 and GOS-E scores, agreement between these measures was poor (unweighted κ 0·094; weighted κ 0·170) (*Table 2*). When the population was restricted to patients meeting pFCI assumptions for single-injury status and co-morbidity, weighted and unweighted κ values were slightly (but not significantly) lower. When the population was further restricted to the 1939 patients meeting all pFCI assumptions, the weighted κ was significantly higher (0·244), although agreement was still only 'slight'[28].

Two-thirds of patients (1300 of 1939, 67·0 per cent) had less than a full recovery at 12 months using the GOS-E (*Table 3*). However, 1284 (66·2 per cent) of the 1939 patients were predicted to have no or minimal functional loss using the pFCI08. Some 44·9 per cent of patients (576 of 1284) had moderate or severe disability at 12 months, and 38·0 per cent had achieved the highest level of function as measured by the GOS-E. The pFCI08 correctly predicted the severe functional loss of the two patients with the lowest level of GOS-E function. However, almost half of the patients (32 of 69, 46 per cent) with the lower severe disability level using GOS-E had little or no functional loss predicted by pFCI08.

Sensitivity analyses testing patient age assumption

Amongst patients meeting other pFCI assumptions, unweighted and weighted κ values gradually decreased as the age restriction lessened (*Table 2*). Assessed weighted κ remained at or above 0·20 up to an 18–69-year age grouping containing 2·6 times as many patients (5076) as the age group of 18–34 years. Only the addition of patients aged 70 years or above lowered assessed κ to the extent that it differed significantly from that seen in patients aged 18–34 years. Unweighted κ values for agreement between pFCI08 and GOS-E scores did not differ significantly from one another for any of the population groupings used (*Table 2*).

Performance of AIS08 in predicting outcome

κ agreement between AIS08 and GOS-E scores was poor. In all three populations assessed, unweighted κ was no higher than 0·03, and weighted κ no higher than 0·09 (*Table 2*). Unweighted and weighted κ agreements between AIS08 and GOS-E were significantly lower than those between pFCI08 and GOS-E.

Discussion

In isolation, the pFCI08 cannot adequately predict individual outcomes following severe injury. The agreement between pFCI08 and GOS-E surpasses that between GOS-E and AIS08. However, owing to the mortality bias known to exist in AIS severity estimates[11,12], this finding is unsurprising. The use of scales derived (wholly or partly) from anatomical injury scores to predict long-term health and functional status necessarily assumes that anatomical injury is directly and substantially predictive of outcome. However, there are many other factors that are associated with outcome following injury[15,23,29–38]; as such, high levels of association are unlikely to be found by any study evaluating only predictions from anatomical injury scores. The present study demonstrated only slight agreement between predicted outcomes from the pFCI08 (based on expert opinion regarding the results of anatomical injuries) and observed 12-month GOS-E outcomes following severe injury. This was despite restricting the population assessed to the fraction of patients meeting the narrow assumptions made by the developers of the pFCI. This confirms the findings of earlier studies[13,39,40] that scales derived from AIS classification of anatomical injury explain only a small proportion of the variability in trauma outcomes. As a result, it is currently unclear whether the pFCI08 (in some form) may be able to contribute meaningfully to any inclusive model attempting to predict functional outcomes following injury.

The developers of the pFCI based pFCI outcome predictions on the arbitrary assumption that patients were aged between 18 and 34 years. However, this subgroup differs from the overall population in terms of sex, mechanism of injury, compensability and overall severity (*Table 1*) – important factors known to influence outcomes following trauma[15]. Using weighted κ values, agreement between pFCI08 and GOS-E was significantly poorer when patients with co-morbidity or multiple injuries were included in the population. When these were controlled for, however, increasing the age range of the patients assessed did not significantly decrease the predictive power of the pFCI08. As a result, although the single-injury and co-morbidity assumptions made by the pFCI developers appear necessary for population homogeneity and improved predictive ability, the age assumption does not.

Some disagreement between predicted and observed outcomes is to be expected. The highest levels of function measured by the tools used are not necessarily equivalent to full recovery with no functional limitations. In addition, the domains of function assessed by the GOS-E[3] and the pFCI[7,8,15] differ somewhat; the GOS-E assesses function within daily activities irrespective of the specific dimension of function that may be impaired[24]. However, in the present study almost half of the patients whom the pFCI08 predicted would not have ongoing functional loss were more than one level of function away from the highest level of the GOS-E. Conversely, patients who were predicted to have substantial functional loss with the pFCI08 comprised 23·6 per cent of patients (151 of 639) who were assessed at the highest level of recovery using GOS-E (*Table 3*). Even using the GOS-E truncation that gave the best agreement with pFCI08 predictions, more than one-quarter of patients (544 of 1939, 28·1 per cent) had a difference between predicted and observed levels of function of more than one level on a five-level scale. This may also have been related to ceiling effects affecting the pFCI08 in particular, as the majority of patients with valid pFCI08 scores (9129 of 17 906, 51·0 per cent; *Table 1*) were expected to have no significant limitations 12 months after severe trauma.

Based on the results of the present study, the pFCI08 outperforms the original pFCI, which returned a weighted κ of only 0·05[13]. However, there were three principal differences between the designs of the present study and that of Schluter and colleagues[13], which assessed weighted κ between predicted and actual outcomes using the original pFCI. First, their study population was not limited to patients with major trauma in a defined population, but to patients admitted to one of two trauma centres for more than 24 h. It is likely that this population would have a higher incidence of isolated, less severe, injuries such as orthopaedic injuries, for which the pFCI is known to over-predict recovery[41]. This may have negatively affected the κ value as assessed by Schluter *et al.*[13] Second, the method used by Schluter and co-workers[13] to weight κ scores was not specified, and may have differed from the quadratic weighted method used in the present study. Third, Schluter *et al.*[13] did not restrict the age of the patient population used to assess the pFCI, and did not collect data relating to preinjury health. Although different age groupings were presented, it may be inferred from the tabulations provided[13] that no more than half of the population was aged between 18 and 34 years, and that a substantial proportion was aged less than 18 or more than 54 years. This may also have affected the reported κ values. As a result, although some authors[14] have claimed that the revised version of the pFCI offers improved morbidity prediction, outcome predictions made using pFCI08 may not be meaningfully better than those using the original pFCI.

More informed use of the pFCI08 may increase the proportion of variability in outcome that can be attributed directly to the injuries sustained. For example, there is known to be variability in the predictive ability of the pFCI for injuries in different body regions, or in the presence of multitrauma[15,42]. It is not known, however, to what extent this variability derives from inaccuracies in the development of the pFCI (where assumptions are made about recovery from a particular AIS injury or injury type) or from actual variability in recovery from these injuries (where a particular AIS code or group of codes applies to a heterogeneous group of patients in terms of their recovery). Exploring the variability between assessed outcomes and the functional predictions made by the pFCI08 across different types of injury may improve the overall utility of this tool, either in isolation or within an as-yet undeveloped model predicting functional outcomes across a population.

The pFCI08 is a truncated version of the larger pFCI, which was updated around 2005[15]. The utility of this version has been evaluated in only a single study[42], which suggested a weak correlation between the pFCI and assessed outcomes using the physical component of the Short Form 36 tool. However, there were a number of methodological concerns with this study[15]. In addition, this version of the pFCI is not widely available[15]. Although a number of methods have been suggested for deriving overall patient pFCI scores using subscores across the dimensions assessed by the pFCI[17], the superiority of any one method has not been assessed[15]. As a result, it is not currently known whether outcome predictions using the widely available pFCI08 are different, or inferior, to those of the larger pFCI.

This study had particular strengths in the inclusive and complete population capture of the VSTR and the high rate of patient follow-up. However, a notable limitation to this study is that the VSTR assesses only long-term outcomes within the major trauma population. Other authors[36,43] have found that a substantial proportion of the morbidity burden following trauma may arise from injuries that have low severity using AIS coding. As a result, estimates of the predictive ability of the pFCI using trauma registries such as the VSTR will be biased towards injuries causing functional loss that have a higher AIS severity (such as head or spinal injury), and away from injuries known to result in functional loss but not generally classified as severe injury (such as lower leg and 'whiplash'-type injuries). In addition, because it was not feasible within the scope of the present study to assess adequately the quality of care received by each patient, the FCI developers' assumption relating to timely and appropriate care could not be evaluated. However, any variations in care (whether systematic or *ad hoc*) are likely to affect the predictive ability of both AIS and pFCI08 severities.

The pFCI08 has only 'slight' agreement with actual outcomes following major trauma, even when restricted to the population for which the tool was developed. However, this agreement appears to be superior to that assessed with the original version of the pFCI, or with AIS codes. Provided that patients are otherwise healthy before injury, the present study suggests that the age restrictions imposed by the pFCI developers may be widened without significant loss of predictive power, at the gain of an expanded population for assessing the performance of the pFCI08. These results also indicate that the pFCI may be able to contribute to the predictive ability of future scoring systems attempting to predict functional outcome following severe injury. However, in any such system it is likely that scores derived from anatomical injury will explain only a small proportion of the variability in patient outcomes.

Disclosure

The authors declare no conflict of interest.

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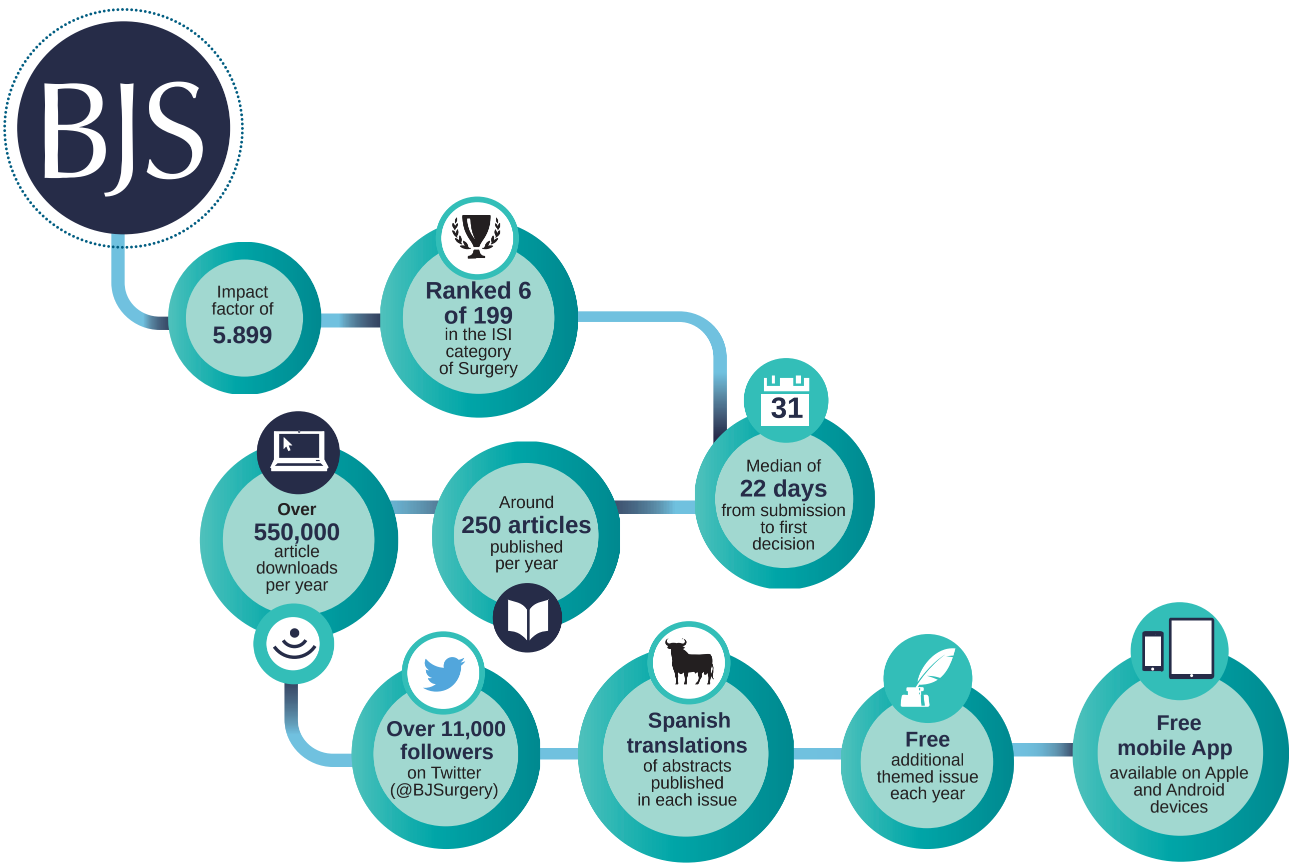
Supporting information

Additional supporting information may be found online in the supporting information tab for this article.



5.3 Summary

Anatomical injury is known to be only one factor amongst many which are associated with outcome following trauma. The outcome predictions made by FCI injury severities significantly outperformed injury severities from the mortality-weighted AIS. However, the agreement between the FCI and actual 12-month outcomes was only slight. Many patients with poor functional outcomes had little or no functional limitations predicted by the FCI, while almost one third of patients with the poorest FCI predictions (69 of 217, 31.8%; Table 3) were assessed as having made a 'good recovery' at 12 months.

Although the population-based dataset used in this study comprised more than 20,000 major trauma patients, less than 10% of these (1,939 patients) met all of the restrictive assumptions made by the FCI's developers. Outcome predictions made by the FCI would not be useful on such a narrow subset of the population. However, it was found that the age restriction could be widened substantially without significantly lowering the predictive performance of the FCI, particularly when other factors were controlled for.

This paper assessed the agreement between anatomical injury and 12-month functional outcome, where injury was defined using either AIS or FCI severities. However, both the AIS and FCI provide estimates of injury 'severity' based on a simple ordinal rating and a structure for classifying these injuries. Consequently, it is unclear whether the comparatively low levels of agreement assessed were due to deficiencies in how the AIS and FCI classify injury, or because anatomical injury (as measured using any system) only explains a small proportion of the variability in patient outcomes - or both. As such, further investigation of the performance of the FCI in predicting outcomes following injury - specifically, whether injury as described by the FCI can add to a predictive model for trauma outcomes - is warranted.

Chapter Six

Predicting Outcomes Using the AIS and FCI

6.1 Overview of Chapter

The truncated FCI contained in the 2008 AIS dictionary has been shown to provide 12-month outcome predictions which vary considerably at an individual level. Overall, though, the study performed in Chapter Five showed that the FCI demonstrated some agreement with actual functional outcomes as assessed using the extended Glasgow Outcome Scale (GOS-E).[166] Moreover, in single-injury major trauma patients the FCI's severity estimates showed significantly higher agreement with outcomes than mortality-weighted AIS severities. However, the utility of the FCI in predicting outcomes in multi-trauma patients has not been assessed.

The paper presented in this chapter used a simple predictive model of age and gender to obtain baseline outcome predictions across a suite of dichotomised outcome measures including the GOS-E, return to work, and the various dimensions of function covered by the EQ-5D-3L health status measure.[167] Additional gains in predictive value were then sought by adding several AIS-based and FCI-based assessments of injury severity. In doing so, a number of methods of utilising the FCI to describe the overall functional severity of multiple injuries were trialled.

The following paper, 'Comparison of revised Functional Capacity Index scores with Abbreviated Injury Scale 2008 scores in predicting 12-month severe trauma outcomes' was accepted for publication by Injury Prevention in February 2019, and published online ahead of print in March 2019. It is currently available online via the following link:

https://injuryprevention.bmj.com/content/early/2019/03/29/injuryprev-2018-043085

Three supplementary files are referred to in this paper, and have been included in this thesis as Appendix Four.

6.2 Published Paper

Comparison of revised Functional Capacity Index scores with Abbreviated Injury Scale 2008 scores in predicting 12-month severe trauma outcomes

Declaration for Thesis Chapter Six

Palmer CS, Cameron PA, Gabbe BJ. Comparison of revised Functional Capacity Index scores with Abbreviated Injury Scale 2008 scores in predicting 12-month severe trauma outcomes. doi: 10.1136/injuryprev-2018-043085.

In the case of Chapter Six, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Study conception and design; statistical testing; development of tables and figures; manuscript drafting and revision	70%

The following co-authors contributed to the work. There are no student co-authors.

Name	Nature of contribution
Belinda Gabbe	Conception and design of study, and manuscript revision
Peter Cameron	Conception and design of study, and manuscript revision

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the candidate's and co-authors' contributions to this work.

Candidate's signature	[redacted]	Date: 1 July 2019
Main supervisor's signature	[redacted]	Date: 1 July 2019

Comparison of revised Functional Capacity Index scores with Abbreviated Injury Scale 2008 scores in predicting 12-month severe trauma outcomes

Cameron S Palmer,[1,2] Peter A Cameron,[2,3] Belinda J Gabbe[2,4]

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[1]Trauma Service, Royal Children's Hospital Melbourne, Parkville, Victoria, Australia
[2]Department of Epidemiology and Preventive Medicine, Monash University, Melbourne, Victoria, Australia
[3]Emergency and Trauma Centre, The Alfred Hospital, Melbourne, Victoria, Australia
[4]Health Data Research UK, Swansea University Medical School, Swansea, UK

Correspondence to
Cameron S Palmer, Trauma Service, Royal Children's Hospital Melbourne, Parkville, VIC 3052, Australia; cameron.palmer@rch.org.au

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ABSTRACT

Introduction Anatomical injury as measured by the AIS often accounts for only a small proportion of variability in outcomes after injury. The predictive Functional Capacity Index (FCI) appended to the 2008 AIS claims to provide a widely available method of predicting 12-month function following injury.

Objectives To determine the extent to which AIS-based and FCI-based scoring is able to add to a simple predictive model of 12-month function following severe injury.

Methods Adult trauma patients were drawn from the population-based Victorian State Trauma Registry. Major trauma and severely injured orthopaedic trauma patients were followed up via telephone interview including Glasgow Outcome Scale—Extended, the EQ-5D-3L and return to work status. A battery of AIS-based and FCI-based scores, and a simple count of AIS-coded injuries were added in turn to a base model using age and gender.

Results A total of 20 813 patients survived to 12 months and had at least one functional outcome recorded, representing 85% follow-up. Predictions using the base model varied substantially across outcome measures. Irrespective of the method used to classify the severity of injury, adding injury severity to the model significantly, but only slightly improved model fit. Across the outcomes evaluated, no method of injury severity assessment consistently outperformed any other.

Conclusions Anatomical injury is a predictor of trauma outcome. However, injury severity as described by the FCI does not consistently improve discrimination, or even provide the best discrimination compared with AIS-based severity scores or a simple injury count.

INTRODUCTION

Estimating the disease burden arising from injury is vital for guiding prevention and management priorities. However, recovery trajectories following serious injury vary widely and may be influenced by many demographic, epidemiological and psychosocial factors.[1–9] The location, type and extent of anatomical injury have been identified as a predictor of outcomes,[1 2 4 6–8 10 11] but in a number of studies, anatomical injury has explained only a small proportion of outcome variability.[10–12] The AIS[13] provides a widely used codeset for classifying anatomical injury, although the severity assessments contained within each AIS code are known to be biased towards mortality risk.[13 14] The predictive Functional Capacity Index (FCI)[15 16] was developed to predict functional outcomes in trauma survivors 12 months after injury.[13 17] Revised and appended to the 2008 AIS (AIS08),[13] the FCI may provide for injury burden estimates using AIS data routinely collected in trauma registries.[12 18]

A recent study demonstrated that the severity levels assigned within the FCI agreed more closely with assessed 12-month outcomes than AIS severity levels.[12] However, agreement was only 'slight',[19] even after excluding a majority of patients on the basis of age, multi-trauma or the presence of comorbidity. Also, beyond considering the worst FCI severity assigned to a patient's injuries,[16 20] no methods exist for accounting for multiple injuries (whether predicted to be disabling or not) when using the FCI.[9]

This study aimed to determine the extent to which AIS-based and FCI-based scores are able to add to a simple predictive model of 12-month functional outcomes in a severely injured population. A secondary aim of the study was to explore and evaluate potential methods of using FCI scores in instances where patients have sustained multiple injuries.

METHODS

Patients and source

This study used data from severely injured adult trauma patients in the Australian state of Victoria. Patients were drawn from the Victorian State Trauma Registry (VSTR), a well-established population-based registry collecting data on hospitalised major trauma.[21] All Victorian hospitals receiving trauma submit data to the VSTR; complete inclusion and exclusion criteria are published elsewhere.[22] The dataset included patients sustaining blunt or penetrating trauma between January 2007 and June 2015. Patients aged less than 18 years, or sustaining burn or asphyxia injury were excluded as the FCI was not designed for these patients.[16]

The VSTR collects cross-sectional data at several points following injury via standardised telephone interview of survivors to discharge (or their carers).[6] Two subgroups of patients receive this follow-up. The first of these are patients meeting Victorian major trauma criteria.[22] The other subgroup are co-included in the Victorian Orthopaedic Trauma Outcomes Registry,[23] which collects data on orthopaedic trauma admitted for more than 24 hours to one of four large sentinel hospitals. For this study, 12-month follow-up data were used.

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Outcome measures used

The outcomes of interest were as follows:

1. Glasgow Outcome Scale—Extended (GOS-E).[22 24] This 8-point hierarchical scale has been validated for use in general trauma populations.[24] A score of 5 or higher is representative of 'independent living',[25] and this dichotomisation was used.
2. Return to work status. Patients who had been working prior to the injury event were dichotomised depending on whether or not they resumed working.
3. The EQ-5D-3L (EQ-5D).[26] This generic measure of health status, including five items (mobility, self-care, usual activities, pain or discomfort, and anxiety or depression) measured on a three-level scale (no, some or severe problems) has been recommended for evaluating trauma patients.[27] Responses to each item were dichotomised into 'no problems' and 'some/severe problems'.[28]

Injury summary scores used

Nearly 10% of the AIS08's 1999 codes either do not have FCI severities assigned (88 codes—52 relating to blunt or penetrating injury), or represent minor superficial injuries with both AIS level one and FCI level 5 (90 codes). These injuries were excluded from analysis. They are listed in online supplementary file 1, along with their incidence in the study dataset. In order to evaluate the FCI as a single tool, a pragmatic approach was used to compare overall discrimination using FCI-based and AIS-based summary scores. This necessitated the development of two scores using FCI-based severities; their rationale and structure are described in online supplementary file 2. The following scores were employed:

1. Three well-established AIS-based summary scores: (i) MAIS[29]; (ii) ISS[30]; (iii) new ISS (NISS).[31]
2. One established, and two novel, FCI-based summary scores: (i) worst FCI[9 16 20]; (ii) Functional Capacity Additive Score (FCAS), a novel score which adjusts and adds the FCI severity levels of up to three worst injuries; and (iii) Functional Capacity Quadratic Score (FCQS), a novel score which adjusts and adds the squared FCI severity levels of up to three worst injuries in a similar manner to the NISS.
3. The total number of injuries (AIS codes) sustained. This functioned as an additional summary score independent of AIS or FCI severities.

Data analysis

Logistic regression was employed to test the predictive capacity of injury summary scores for each outcome. A split dataset approach using a 2:1 ratio was used, randomising cases to the 'training' dataset used to develop the model or the 'testing' dataset used to validate it. Predictors were not categorised, to avoid statistical inefficiency and loss of predictive power.[32]

The base model used only age[1–3 6 7 9] and gender,[2 7 9 25] which are well-recognised and universally comparable predictors of trauma outcome. Patient age was not restricted, although sensitivity analyses with restricted age groups[15 16] were performed and reported as supplementary data (online supplementary file 3).

Injury severity measures were added to the base model in turn. Ungrouped standardised Pearson χ^2 tests were used to assess calibration in preference to the Hosmer-Lemeshow test, as many of the quantiles had substantial numbers of ties.[33 34] Discrimination was assessed using the area under the receiver operating characteristic curve (AUC); Gönen's method was used to compare AUCs including injury severity measures.[35] Proportions were assessed with χ^2chi square testing, including evaluation of standardised residuals.

All analyses were performed using Stata V.14.0 (StataCorp, College Station, Texas, USA). A p value less than 0.005 was considered significant[36]; CIs and standardised residuals were reported at the 99% level.

RESULTS

Derivation and description of the dataset

A total of 28 793 adult patients with blunt or penetrating trauma were retrieved from the VSTR (figure 1). Loss to follow-up was low; of the 26 077 patients who survived to hospital discharge, 85.3% had a known 12-month outcome (figure 1).

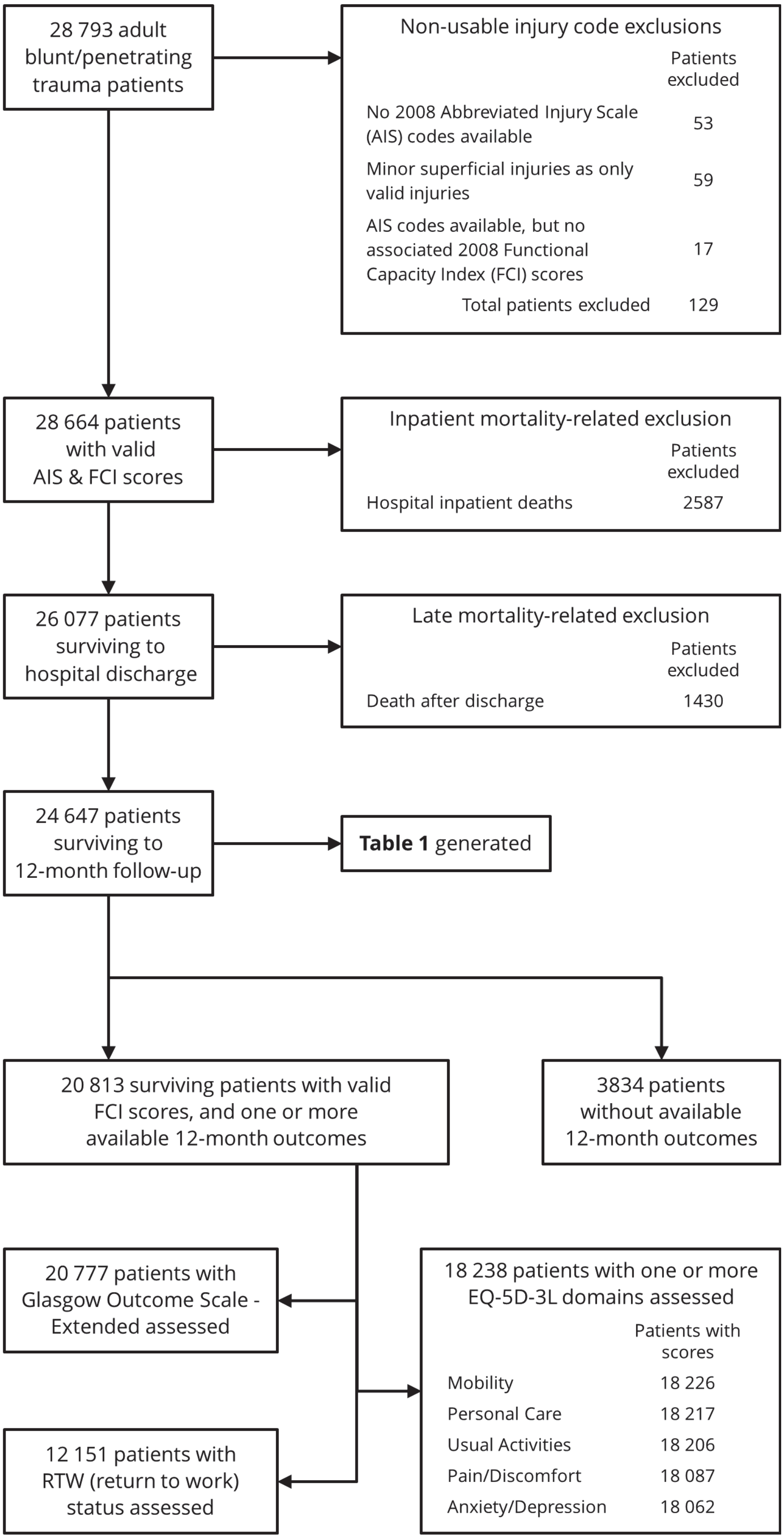
Surviving patients with valid AIS and FCI data available are summarised in table 1. Patients lost to follow-up were more likely to be aged less than 45 years, and to reside in a socio-economically disadvantaged area, based on the 2011 Australian census.[37] They sustained fewer falls injuries, and a higher proportion of penetrating (piercing, cutting or gunshot) and intentional injury or injury of unknown intent. These patients were also more likely to sustain injuries to 'other' regions such as the chest or abdomen, or to sustain only injuries of FCI level 5.

Splitting of patients into training and testing datasets returned comparable datasets (table 1); the training dataset comprised 13 885 patients, and the testing dataset 6928 patients out of a total of 20 813 patients with at least one outcome recorded. Of these (n=20 777), 99.8% had GOS-E scores recorded, and most (18 238; 87.6%) had one or more EQ-5D items recorded. In total, 12 283 patients (59.0%) had been working prior to injury; of these, almost all (12 151; 98.9%) had return to work status recorded, with the most common pre-injury occupation groups being tradespersons (28%), professional workers (14%) and clerical or service staff (12%). Most patients sustained multiple injuries (across one or more body regions); only 3468 of 20 813 patients with 12-month outcomes (16.7%) sustained a single, non-superficial injury.

Training dataset

The base model of age and gender alone varied substantially in predicting functional outcomes; predictions for return to work and the EQ-5D items of pain/discomfort and anxiety/depression were little better than chance, while predictions of GOS-E had an AUC of 0.762 (table 2). Irrespective of the summary score used, adding injury to the model significantly improved model fit; the sole exception was the addition of NISS in the prediction of EQ-5D pain/discomfort (table 2). Models using the FCAS produced the highest AUC for return to work and the EQ-5D mobility and usual activities items, and models using the FCQS the highest AUC for the GOS-E and EQ-5D personal care item. However, models using the simple count of the number of injuries produced the highest AUC for the EQ-5D pain/discomfort and anxiety/depression items (table 2). Models only exceeded an AUC of 0.70 for three outcomes—GOS-E and the EQ-5D mobility and personal care items—and were never higher than 0.60 for the EQ-5D pain/discomfort and anxiety/depression items. Models predicting GOS-E were not well calibrated, but models predicting other outcomes were generally well calibrated (table 2).

No method of injury severity assessment consistently outperformed any other (table 2). The variability in discrimination across each outcome was often small—for example, all of the injury-adjusted models predicting the EQ-5D personal care item



[a] AIS - 2008 Abbreviated Injury Scale
[b] FCI - 2008 predictive Functional Capacity Index

Figure 1 Flow diagram showing derivation of the study dataset, including the number of patients with available data for each outcome measure used.

Table 1 Demographics and injury severity of surviving Victorian major and severe orthopaedic trauma patients with valid AIS and Functional Capacity Index (FCI) data available (percentages for each breakdown are shown in brackets and do not always add to 100% due to rounding)

	Training dataset	Testing dataset	Lost to follow-up	Total
Total patients	13 885	6928	3834	24 647
Gender				
Male	9661 (70)	4740 (68)	2734 (71)	17 135 (70)
Female	4224 (30)	2188 (32)	1100 (29)	7512 (30)
Age group				
18–24 years	1930 (14)	1002 (14)	712 (19)	3644 (15)
25–34 years	2003 (14)	1000 (14)	840 (22)	3843 (16)
35–44 years	1972 (14)	951 (14)	669 (17)	3592 (15)
45–54 years	2053 (15)	961 (14)	493 (13)	3507 (14)
55–64 years	1774 (13)	906 (13)	364 (9)	3044 (12)
65–74 years	1594 (11)	784 (11)	265 (7)	2643 (11)
75–84 years	1606 (12)	849 (12)	299 (8)	2754 (11)
85 + years	953 (7)	475 (7)	192 (5)	1620 (7)
Comorbidity present				
Healthy (CCI*=0)	9385 (68)	4698 (68)	2657 (69)	16 740 (68)
Comorbidity (CCI*>0)	4500 (32)	2230 (32)	1177 (31)	7907 (32)
IRSAD decile†				
First quintile (most disadvantaged)	1860 (13)	900 (13)	653 (17)	3413 (14)
Second quintile	1921 (14)	999 (14)	536 (14)	3456 (14)
Third quintile	2752 (20)	1421 (21)	742 (19)	4915 (20)
Fourth quintile	3093 (22)	1521 (22)	697 (18)	5311 (22)
Fifth quintile (most advantaged)	3940 (28)	1905 (28)	966 (25)	6811 (28)
Unknown	319 (2)	182 (3)	240 (6)	741 (3)
Intent of injury				
Unintentional	12 668 (91)	6335 (91)	3096 (81)	22 099 (90)
Intentional (assault or self-harm)	1030 (7)	507 (7)	632 (16)	2169 (9)
Other or unspecified intent	187 (1)	86 (1)	106 (3)	379 (2)
Compensability of injuries				
Compensable	6075 (44)	3031 (44)	1589 (41)	10 695 (43)
Non-compensable	7810 (56)	3897 (56)	2245 (59)	13 952 (57)
Mechanism of injury				
Occupant in motor vehicle	3159 (23)	1612 (23)	887 (23)	5658 (23)
Other transport-related	3490 (25)	1712 (25)	828 (22)	6030 (24)
Fall ≤1 m	3344 (24)	1746 (25)	803 (21)	5893 (24)
Fall >1 m	1788 (13)	841 (12)	406 (11)	3035 (12)
Piercing, cutting or gunshot	414 (3)	193 (3)	294 (8)	901 (4)
Other mechanism	1690 (12)	824 (12)	616 (16)	3130 (13)
Reason for VSTR‡ inclusion				
Major trauma	4503 (32)	2232 (32)	1718 (45)	8453 (34)
Orthopaedic trauma	4300 (31)	2147 (31)	1124 (29)	7571 (31)
Major and orthopaedic trauma	5082 (37)	2549 (37)	992 (26)	8623 (35)
Maximum AIS score				
1	48 (0)	21 (0)	31 (1)	100 (0)
2	3572 (26)	1788 (26)	1061 (28)	6421 (26)
3	6206 (45)	3063 (44)	1716 (45)	10 985 (45)
4	2713 (20)	1350 (19)	687 (18)	4750 (19)
5	1340 (10)	705 (10)	337 (9)	2382 (10)
6	6 (0)	1 (0)	2 (0)	9 (0)
Worst FCI score				
5 (best outcome)	7372 (53)	3667 (53)	2300 (60)	13 339 (54)
4	2308 (17)	1191 (17)	555 (14)	4054 (16)
3	1079 (8)	494 (7)	265 (7)	1838 (7)
2	1421 (10)	736 (11)	298 (8)	2455 (10)
1 (worst outcome)	1705 (12)	840 (12)	416 (11)	2961 (12)
ISS grouping§				
1–8	2710 (20)	1363 (20)	812 (21)	4885 (20)
9–12	2741 (20)	1342 (19)	762 (20)	4845 (20)
13–14	2283 (16)	1109 (16)	831 (22)	4223 (17)
16–19	2706 (19)	1402 (20)	657 (17)	4765 (19)
20–24	1283 (9)	620 (9)	265 (7)	2168 (9)
25–38	1934 (14)	971 (14)	448 (12)	3353 (14)
41–48	143 (1)	76 (1)	34 (1)	253 (1)
50–75	85 (1)	45 (1)	25 (1)	155 (1)
Body regions injured				
Head only	1446 (10)	729 (11)	371 (10)	2546 (10)
Head + spinal cord	269 (2)	125 (2)	42 (1)	442 (2)
Head + other	4098 (30)	2065 (30)	1067 (28)	7230 (29)
Other spinal cord	603 (4)	290 (4)	150 (4)	1043 (4)
Orthopaedic only	3365 (24)	1688 (24)	865 (23)	5918 (24)
Orthopaedic + other	3174 (23)	1569 (23)	878 (23)	5621 (23)
Other	930 (7)	462 (7)	455 (12)	1847 (7)

*CCI—Charlson Comorbidity Index.
†IRSAD—Index of Relative Socio-economic Advantage and Disadvantage.
‡VSTR—Victorian State Trauma Registry.
§Not all ISS values (such as 15, 39, 40 and 49) are obtainable, due to the construction of the ISS.

varied between 0.717 and 0.727 (table 2; figure 2). There was no significant difference between any of the injury-adjusted models for two of the physical outcomes (GOS-E and the personal care item of the EQ-5D) and one psychosocial outcome (the pain/discomfort item of the EQ-5D). On two of the outcome measures (the mobility and usual activities items of the EQ-5D), all AIS-based models performed significantly worse than the highest (FCI-based) model. However, among models predicting the EQ-5D anxiety/depression item, the second-highest discrimination (after the number of injuries) was the model containing the ISS (table 2).

Testing dataset

When the same models were fitted to the testing dataset, results were similar (table 3). All injury scores improved model fit for all outcomes, with the exception of the MAIS for predicting the EQ-5D usual activities item, or any AIS-based score for the EQ-5D pain/discomfort item. Again, no single method of injury adjustment consistently produced higher discrimination. The number of injuries sustained produced the highest AUC when predicting return to work or the EQ-5D pain/discomfort and anxiety/depression items, the FCAS for the EQ-5D mobility and usual activities items, the FCQS for the EQ-5D personal care item and the MAIS the highest AUC when predicting GOS-E.

Table 2 Discrimination and calibration of models in the training dataset (total n=13 885 patients)

Model outcome	Area under ROC curve (99% CI)	Ungrouped Pearson χ^2 statistic (p value)	LR test (p value)*	χ^2 difference to highest AUC† (p value)
GOS-E§§ outcome	**(n=13 866)**			
Age and gender	0.762 (0.748 to 0.777)	15 492.2 (<0.0001)	–	–
Age, gender and no of injuries	0.769 (0.755 to 0.783)	15 265.0 (<0.0001)	64.70 (<0.0001)	4.64 (0.031)
Age, gender and MAIS‡	0.779 (0.766 to 0.793)	14 865.7 (0.0005)	270.73 (<0.0001)	0.53 (0.467)
Age, gender and ISS§	0.781 (0.768 to 0.794)	14 934.4 (0.0007)	257.42 (<0.0001)	0.26 (0.611)
Age, gender and NISS¶	0.779 (0.766 to 0.793)	14 922.7 (0.0007)	225.86 (<0.0001)	0.55 (0.458)
Age, gender and worst FCI**	0.779 (0.766 to 0.792)	14 647.4 (0.001)	232.38 (<0.0001)	0.58 (0.446)
Age, gender and FCAS††	0.778 (0.765 to 0.791)	14 831.9 (<0.0001)	201.51 (<0.0001)	0.85 (0.358)
Age, gender and FCQS‡‡	0.785 (0.772 to 0.798)*	14 809.0 (0.005)	308.62 (<0.0001)	–
Return to work outcome	**(n=8132)**			
Age and gender	0.527 (0.509 to 0.545)	8132.7 (0.987)	–	–
Age, gender and no of injuries	0.632(0.614 to 0.650)	8126.0 (0.922)	382.79 (<0.0001)	3.30 (0.069)
Age, gender and MAIS‡	0.601 (0.583 to 0.618)	8125.6 (0.912)	222.37 (<0.0001)	25.27 (<0.0001)†
Age, gender and ISS§	0.627 (0.610 to 0.645)	8149.1 (0.789)	373.85 (<0.0001)	5.25 (0.021)
Age, gender and NISS¶	0.622 (0.604 to 0.639)	8118.0 (0.817)	321.79 (<0.0001)	8.24 (0.004)†
Age, gender and worst FCI**	0.637 (0.619 to 0.655)	8118.7 (0.039)	373.10 (<0.0001)	1.72 (0.190)
Age, gender and FCAS††	0.650 (0.632 to 0.667)*	8118.8 (0.542)	491.36 (<0.0001)	–
Age, gender and FCQS‡‡	0.643 (0.625 to 0.661)	8106.5 (0.661)	437.77 (<0.0001)	0.22 (0.640)
EQ-5D mobility outcome	**(n=12 200)**			
Age and gender	0.683 (0.670 to 0.696)	12 264.5 (0.485)	–	–
Age, gender and no of injuries	0.702 (0.689 to 0.714)	12 271.2 (0.471)	202.02 (<0.0001)	12.39 (0.004)†
Age, gender and MAIS‡	0.688 (0.675 to 0.700)	12 258.9 (0.419)	54.67 (<0.0001)	31.30 (<0.0001)†
Age, gender and ISS§	0.694 (0.681 to 0.706)	12 267.1 (0.466)	116.37 (<0.0001)	21.97 (<0.0001)†
Age, gender and NISS¶	0.690 (0.678 to 0.703)	12 255.7 (0.528)	73.55 (<0.0001)	26.97 (<0.0001)†
Age, gender and worst FCI**	0.720 (0.708 to 0.732)	12 214.2 (0.737)	462.71 (<0.0001)	0.75 (0.386)
Age, gender and FCAS††	0.725 (0.713 to 0.737)*	12 253.6 (0.018)	544.76 (<0.0001)	–
Age, gender and FCQS‡‡	0.720 (0.708 to 0.732)	12 275.4 (0.496)	454.96 (<0.0001)	0.34 (0.561)
EQ-5D personal care outcome	**(n=12 196)**			
Age and gender	0.710 (0.696 to 0.725)	12 511.0 (0.068)	–	–
Age, gender and no of injuries	0.722 (0.709 to 0.736)	12 462.5 (0.129)	121.95 (<0.0001)	0.27 (0.600)
Age, gender and MAIS‡	0.717 (0.703 to 0.731)	12 410.1 (0.132)	74.32 (<0.0001)	1.58 (0.208)
Age, gender and ISS§	0.721 (0.707 to 0.735)	12 408.8 (0.210)	108.61 (<0.0001)	0.56 (0.455)
Age, gender and NISS¶	0.718 (0.704 to 0.732)	12 415.6 (0.187)	83.34 (<0.0001)	1.10 (0.293)
Age, gender and worst FCI**	0.723 (0.709 to 0.737)	12 348.9 (0.209)	140.17 (<0.0001)	0.19 (0.666)
Age, gender and FCAS††	0.725 (0.711 to 0.739)	12 372.6 (0.049)	161.66 (<0.0001)	0.02 (0.875)
Age, gender and FCQS‡‡	0.727 (0.713 to 0.740)*	12 381.5 (0.313)	180.47 (<0.0001)	–
EQ-5D usual activities outcome	**(n=12 186)**			
Age and gender	0.598 (0.585 to 0.611)	12 173.4 (0.663)	–	–
Age, gender and no of injuries	0.632 (0.619 to 0.645)	12 190.1 (0.923)	269.93 (<0.0001)	0.82 (0.365)
Age, gender and MAIS‡	0.601 (0.588 to 0.614)	12 173.9 (0.642)	24.19 (<0.0001)	27.27 (<0.0001)†
Age, gender and ISS§	0.613 (0.600 to 0.626)	12 176.9 (0.804)	105.00 (<0.0001)	12.95 (0.0003)†
Age, gender and NISS¶	0.609 (0.596 to 0.622)	12 177.5 (0.806)	76.38 (<0.0001)	16.83 (0.0004)†
Age, gender and worst FCI**	0.630 (0.617 to 0.643)	12 201.1 (0.005)	223.25 (<0.0001)	1.41 (0.235)
Age, gender and FCAS††	0.639 (0.626 to 0.651)*	12 213.2 (0.171)	315.56 (<0.0001)	–
Age, gender and FCQS‡‡	0.632 (0.619 to 0.645)	12 214.5 (0.495)	246.46 (<0.0001)	0.38 (0.535)
EQ-5D pain/discomfort outcome	**(n=12 109)**			
Age and gender	0.530 (0.517 to 0.544)	12 108.9 (0.959)	–	–
Age, gender and no of injuries	0.584 (0.571 to 0.597)*	12 121.6 (0.505)	234.90 (<0.0001)	–
Age, gender and MAIS‡	0.540 (0.527 to 0.554)	12 109.0 (0.998)	13.13 (0.0003)	35.47 (<0.0001)†
Age, gender and ISS§	0.538 (0.525 to 0.551)	12 108.8 (0.949)	15.27 (0.0001)	39.30 (<0.0001)†
Age, gender and NISS¶	0.535 (0.521 to 0.548)	12 108.9 (0.926)	2.72 (0.099)	45.31 (<0.0001)†
Age, gender and worst FCI**	0.549 (0.535 to 0.562)	12 109.6 (0.953)	36.58 (<0.0001)	23.04 (<0.0001)†
Age, gender and FCAS††	0.570 (0.557 to 0.584)	12 114.6 (0.765)	105.11 (<0.0001)	3.62 (0.057)
Age, gender and FCQS‡‡	0.554 (0.541 to 0.568)	12 111.1 (0.552)	39.84 (<0.0001)	8.32 (0.004)†
EQ-5D anxiety/depression outcome	**(n=12 082)**			
Age and gender	0.544 (0.530 to 0.558)	12 080.9 (0.944)	–	–

Continued

Table 2 Continued

Model outcome	Area under ROC curve (99% CI)	Ungrouped Pearson χ^2 statistic (p value)	LR test (p value)*	χ^2 difference to highest AUC† (p value)
Age, gender and no of injuries	0.574 (0.560 to 0.587)*	12 080.9 (0.967)	120.04 (<0.0001)	–
Age, gender and MAIS‡	0.555 (0.541 to 0.569)	12 081.9 (0.996)	37.56 (<0.0001)	5.81 (0.016)
Age, gender and ISS§	0.568 (0.554 to 0.582)	12 082.5 (0.985)	99.22 (<0.0001)	0.50 (0.480)
Age, gender and NISS¶	0.566 (0.552 to 0.579)	12 082.6 (0.982)	83.27 (<0.0001)	1.07 (0.301)
Age, gender and worst FCI**	0.557 (0.543 to 0.570)	12 080.7 (0.458)	40.02 (<0.0001)	5.01 (0.025)
Age, gender and FCAS††	0.567 (0.553 to 0.581)	12 080.9 (0.893)	87.11 (<0.0001)	0.78 (0.376)
Age, gender and FCQS‡‡	0.561 (0.547 to 0.574)	12 081.1 (0.965)	64.18 (<0.0001)	1.45 (0.229)

For each outcome, likelihood ratios are compared with the base model of age and gender. The highest area under the ROC curve (AUC) for each outcome is indicated with an asterisk; models including a measure of anatomical injury giving an AUC significantly lower than this (with a χ^2 statistic of 7.879 equivalent to a p value of 0.005) are indicated by an obelisk.
*LR—likelihood ratio test; compared with model with age and gender only.
†AUC—area under the receiver operating characteristic (ROC) curve.
‡MAIS—Maximum 2008 AIS severity.
§ISS—Injury Severity Score.
¶NISS—New Injury Severity Score.
**Worst FCI—worst 2008 predictive Functional Capacity Index score.
††FCAS—Functional Capacity Additive Score (based on three worst FCI scores).
‡‡FCQS—Functional Capacity Quadratic Score (based on up to three worst FCI scores).
§§GOS-E—Extended Glasgow Outcome Scale.

Models predicting GOS-E were again poorly calibrated, but acceptable calibration was observed for other outcomes (table 3; figure 3). While middle-range prediction predictions tracked close to the line of best fit, calibration was poorer at scale extremes. Both the base model and the models incorporating AIS-based injury adjustment tended to overpredict outcomes at lower prediction quantiles, and underpredicted all but GOS-E and the EQ-5D personal care item at higher quantiles.

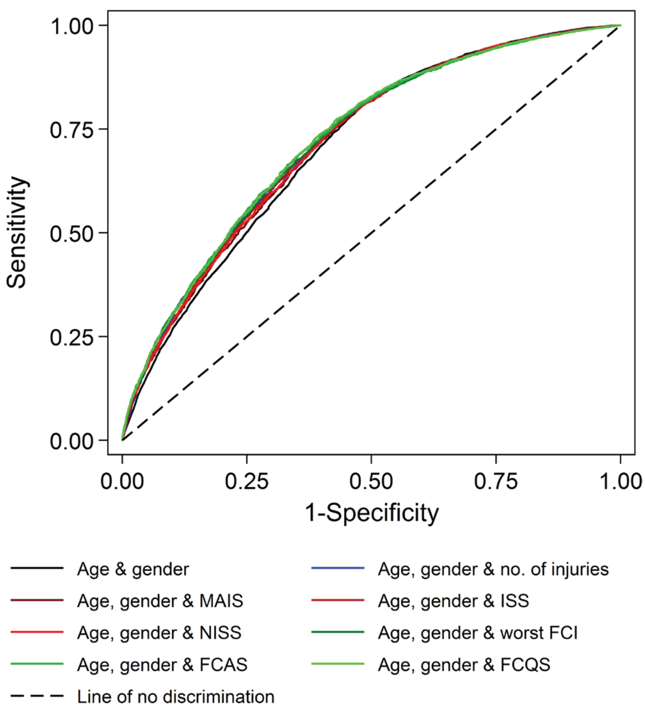


Figure 2 Receiver operating characteristic curves for models used in predicting the EQ-5D personal care item in the training dataset (n=12 196 patients). FCAS, Functional Capacity Additive Score; FCI, Functional Capacity Index; FCQS, Functional Capacity Quadratic Score; MAIS, Maximum 2008 AIS severity; NISS, New Injury Severity Score.

In contrast, models incorporating FCI-based injury adjustment tended to underpredict outcomes at lower quantiles and overpredicted outcomes at higher prediction quantiles.

DISCUSSION

The authors who first presented the FCI stated 20 years ago that, "the FCI must be empirically validated across the full spectrum of injury type and severity… An important aspect of the validation will be the comparison of the FCI with widely accepted performance based and self-reported measures of function".[16] In the present study, the AIS and FCI often performed similarly in improving the prediction of outcomes over models using age and gender alone. The FCI was developed to provide outcomes-weighted severities as an alternative to the mortality-weighted severities in the AIS codeset. In this respect, the FCI is unlikely to be fit for purpose as a global outcome prediction tool.

Previous studies have found associations between anatomical injury and a range of physical outcomes.[1–7 25 28 38] While some studies have found that the ISS is independently associated with functional outcomes,[1 5] others have found that injuries to particular body regions or the presence of multi-trauma contribute variously to different outcome measures.[1–7 38] In the present study, models containing the AIS-based, mortality-weighted ISS significantly improved model performance for all but one outcome, and returned a higher AUC than all FCI-based models in predicting the anxiety/depression outcome of the EQ-5D (table 2).

Although models incorporating injury severity performed relatively well on physical measures, for psychosocial measures (the pain/discomfort and anxiety/depression components of the EQ-5D) they performed little better than chance; this is in keeping with previous findings.[25] Pain and psychosocial outcomes were specifically excluded from the dimensions of function covered by the FCI[15]; this has previously been criticised.[27 39] However, the types of injury—and the non-injury predictors—which contribute to physical outcomes are known to differ from those which contribute to psychosocial outcomes.[4 5 38] As such, it is unlikely that scores using a single severity level for 'outcome' (such as that offered by the AIS or FCI)[13] will satisfactorily add to models predicting both functional (physical) outcomes and quality of life.

Palmer CS, *et al*. *Inj Prev* 2019;**0**:1–9. doi:10.1136/injuryprev-2018-043085

Table 3 Discrimination and calibration of models in the testing dataset (total n=6928 patients)

Model outcome	Area under ROC curve (99% CI)	Ungrouped Pearson χ² statistic (p value)	LR test (p value)*
GOS-E§§ outcome	**(n=6911)**		
Age and gender	0.762 (0.742 to 0.782)	7565.0 (0.002)	–
Age, gender and no of injuries	0.765 (0.746 to 0.785)	7504.5 (0.003)	12.78 (0.0004)
Age, gender and MAIS‡	0.780 (0.761 to 0.799)*	7402.3 (0.017)	143.14 (<0.0001)
Age, gender and ISS§	0.778 (0.759 to 0.796)	7462.2 (0.013)	114.84 (<0.0001)
Age, gender and NISS¶	0.778 (0.760 to 0.797)	7445.6 (0.016)	112.29 (<0.0001)
Age, gender and worst FCI**	0.776 (0.757 to 0.795)	7343.6 (0.012)	95.08 (<0.0001)
Age, gender and FCAS††	0.774 (0.755 to 0.793)	7461.4 (0.0001)	70.46 (<0.0001)
Age, gender and FCQS‡‡	0.779 (0.761 to 0.798)	7449.1 (0.019)	116.07 (<0.0001)
Return to work outcome	**(n=4019)**		
Age and gender	0.538 (0.512 to 0.564)	4018.8 (0.995)	–
Age, gender and no of injuries	0.638 (0.612 to 0.663)	4012.8 (0.894)	213.62 (<0.0001)
Age, gender and MAIS‡	0.605 (0.580 to 0.630)	4019.6 (0.990)	113.25 (<0.0001)
Age, gender and ISS§	0.630 (0.605 to 0.655)	4022.8 (0.936)	184.28 (<0.0001)
Age, gender and NISS¶	0.632 (0.607 to 0.657)	4007.2 (0.800)	176.64 (<0.0001)
Age, gender and worst FCI**	0.629 (0.604 to 0.654)	4017.8 (0.852)	164.88 (<0.0001)
Age, gender and FCAS††	0.638 (0.613 to 0.662)*	4000.2 (0.045)	185.62 (<0.0001)
Age, gender and FCQS‡‡	0.634 (0.609 to 0.659)	4006.6 (0.767)	168.94 (<0.0001)
EQ-5D mobility outcome	**(n=6026)**		
Age and gender	0.702 (0.684 to 0.720)	6053.4 (0.703)	–
Age, gender and no of injuries	0.711 (0.694 to 0.729)	6045.8 (0.779)	44.69 (<0.0001)
Age, gender and MAIS‡	0.705 (0.688 to 0.723)	6043.8 (0.751)	26.08 (<0.0001)
Age, gender and ISS§	0.710 (0.691 to 0.727)	6048.1 (0.750)	47.25 (<0.0001)
Age, gender and NISS¶	0.708 (0.690 to 0.725)	6046.1 (0.764)	32.07 (<0.0001)
Age, gender and worst FCI**	0.728 (0.711 to 0.745)	6031.2 (0.890)	171.34 (<0.0001)
Age, gender and FCAS††	0.731 (0.714 to 0.748)*	6041.1 (0.474)	202.29 (<0.0001)
Age, gender and FCQS‡‡	0.729 (0.712 to 0.746)	6040.7 (0.859)	185.17 (<0.0001)
EQ-5D personal care outcome	**(n=6021)**		
Age and gender	0.727 (0.707 to 0.747)	6171.6 (0.267)	–
Age, gender and no of injuries	0.733 (0.713 to 0.752)	6124.5 (0.426)	22.57 (<0.0001)
Age, gender and MAIS‡	0.733 (0.713 to 0.753)	6166.4 (0.199)	39.69 (<0.0001)
Age, gender and ISS§	0.737 (0.717 to 0.756)	6158.9 (0.303)	56.30 (<0.0001)
Age, gender and NISS¶	0.734 (0.715 to 0.754)	6151.5 (0.316)	38.17 (<0.0001)
Age, gender and worst FCI**	0.739 (0.720 to 0.758)	6095.2 (0.457)	65.67 (<0.0001)
Age, gender and FCAS††	0.738 (0.719 to 0.758)	6117.0 (0.212)	59.05 (<0.0001)
Age, gender and FCQS‡‡	0.740 (0.721 to 0.760)*	6123.3 (0.473)	72.56 (<0.0001)
EQ-5D usual activities outcome	**(n=6020)**		
Age and gender	0.619 (0.601 to 0.638)	6014.7 (0.842)	–

Continued

Table 3 Continued

Model outcome	Area under ROC curve (99% CI)	Ungrouped Pearson χ² statistic (p value)	LR test (p value)*
Age, gender and no of injuries	0.632 (0.614 to 0.651)	6014.0 (0.859)	78.73 (<0.0001)
Age, gender and MAIS‡	0.621 (0.602 to 0.639)	6014.8 (0.811)	9.63 (0.0019)
Age, gender and ISS§	0.625 (0.607 to 0.644)	6013.7 (0.830)	37.42 (<0.0001)
Age, gender and NISS¶	0.623 (0.604 to 0.641)	6014.8 (0.852)	24.14 (<0.0001)
Age, gender and worst FCI**	0.639 (0.620 to 0.657)	6028.2 (0.204)	81.75 (<0.0001)
Age, gender and FCAS††	0.642 (0.624 to 0.660)*	6024.3 (0.522)	110.65 (<0.0001)
Age, gender and FCQS‡‡	0.640 (0.622 to 0.659)	6025.2 (0.876)	89.40 (<0.0001)
EQ-5D pain/discomfort outcome	**(n=5978)**		
Age and gender	0.534 (0.515 to 0.553)	5978.0 (0.904)	–
Age, gender and no of injuries	0.568 (0.549 to 0.587)*	5980.0 (0.827)	64.17 (<0.0001)
Age, gender and MAIS‡	0.539 (0.519 to 0.558)	5977.9 (0.979)	4.08 (0.0433)
Age, gender and ISS§	0.537 (0.518 to 0.556)	5977.8 (0.938)	6.53 (0.0106)
Age, gender and NISS¶	0.535 (0.516 to 0.554)	5978.0 (0.834)	0.22 (0.6400)
Age, gender and worst FCI**	0.548 (0.528 to 0.567)	5978.3 (0.967)	15.43 (0.0001)
Age, gender and FCAS††	0.564 (0.549 to 0.583)	5980.0 (0.865)	43.45 (<0.0001)
Age, gender and FCQS‡‡	0.554 (0.535 to 0.573)	5979.2 (0.712)	20.89 (<0.0001)
EQ-5D anxiety/ depression outcome	**(n=5980)**		
Age and gender	0.543 (0.523 to 0.563)	5980.7 (0.957)	–
Age, gender and no of injuries	0.562 (0.542 to 0.582)*	5981.3 (0.939)	27.87 (<0.0001)
Age, gender and MAIS‡	0.551 (0.531 to 0.570)	5980.7 (0.960)	11.18 (0.0008)
Age, gender and ISS§	0.556 (0.536 to 0.575)	5981.5 (0.929)	25.10 (<0.0001)
Age, gender and NISS¶	0.558 (0.539 to 0.578)	5980.8 (0.962)	23.07 (<0.0001)
Age, gender and worst FCI**	0.553 (0.533 to 0.573)	5981.3 (0.727)	13.02 (0.0003)
Age, gender and FCAS††	0.560 (0.540 to 0.579)	5981.2 (0.493)	23.14 (<0.0001)
Age, gender and FCQS‡‡	0.557 (0.537 to 0.576)	5980.9 (0.956)	18.72 (<0.0001)

For each outcome, likelihood ratios are compared with the base model of age and gender.
The highest area under the ROC curve (AUC) for each outcome is indicated with an asterisk.
*LR—likelihood ratio test; compared with model with age and gender only.
†AUC—area under the receiver operating characteristic (ROC) curve.
‡MAIS—Maximum 2008 AIS severity.
§ISS—Injury Severity Score.
¶NISS—New Injury Severity Score.
**Worst FCI—Worst 2008 predictive Functional Capacity Index score.
††FCAS—Functional Capacity Additive Score (based on three worst FCI scores).
‡‡FCQS—Functional Capacity Quadratic Score (based on up to three worst FCI scores).
§§GOS-E—Extended Glasgow Outcome Scale.

In this context, the performance of the simple number of coded injuries in predicting the outcome measures assessed—particularly the EQ-5D psychosocial dimensions—is unsurprising. The number of injuries has previously been associated with outcome across all dimensions of the EQ-5D.[28] In the present study, the model containing the number of injuries outperformed AIS-based models for all outcomes except GOS-E, although FCI-based models were consistently higher for physical outcome measures including return to work. The present study created two new FCI-based summary scores in order to validate the FCI for these patients. However, none of the AIS-based or FCI-based summary scores used severity data for more than three injuries. Consequently, there may be better ways to use FCI severities in the presence of multiple injuries.

The FCI was designed specifically to provide a function-weighted alternative to the mortality-weighted severities comprising the AIS,[16] and outperformed the AIS in an earlier study assessing

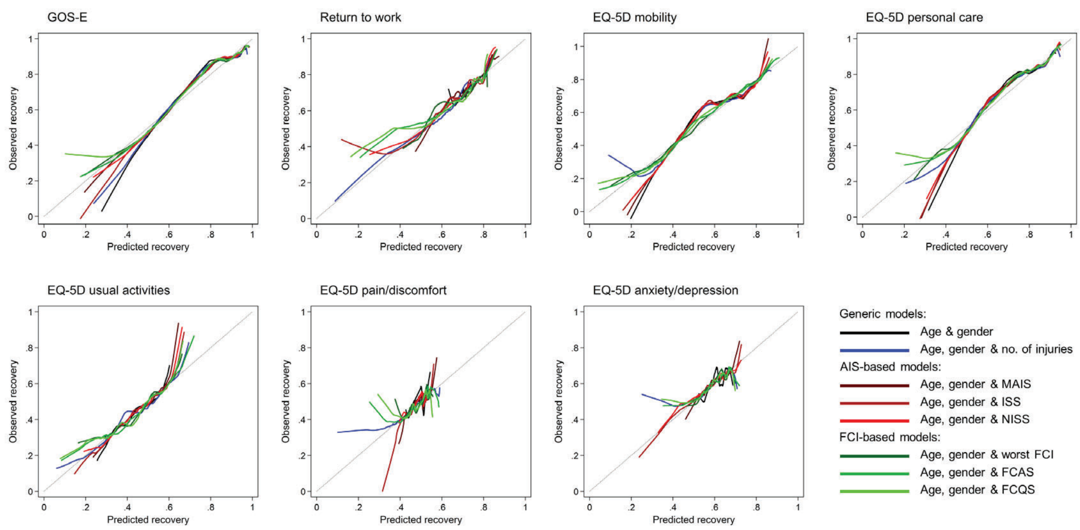


Figure 3 Plots illustrating predicted vs observed recovery in the testing datasets for each outcome variable evaluated. The 45° line shown in each subfigure represents perfect fit of each model. FCAS, Functional Capacity Additive Score; FCI, Functional Capacity Index; FCQS, Functional Capacity Quadratic Score; MAIS, Maximum 2008 AIS severity; NISS, New Injury Severity Score.

agreement between anatomical injury severity and GOS-E.[12] As such, it is unclear why FCI-based scores often provided only marginal gains over AIS-based scores in the present study even when their severities were used in similar ways (as with the NISS and FCQS). The pFCI08's developers used a standard gamble methodology to derive FCI severities.[20] However, these rely on accurate clinician descriptions of the expected functional outcome of each injury and as such may be unsuitable for a highly specific classification system such as the AIS. Previous studies have found greater variability in FCI predictions for injuries to the head, lower limb and spine.[8 17] As a result, it is unsurprising that outcome predictions in a population with mixed major and orthopaedic trauma are less accurate than might be anticipated given the aims of the FCI. However, the exact extent to which anatomical injury predicts different functional outcomes—as estimated using several methods in the present study—remains unclear.

The present study used two novel methods for combining FCI scores in the presence of multiple injuries. This is essential to routine outcome prediction; in the present study, the majority of patients sustained injuries to multiple body regions (table 1). For all but one of the outcomes evaluated, models containing either the FCAS or FCQS generally recorded slightly (although not significantly) higher AUC than the single worst FCI, which was previously the recommended method.[9 16 20] In addition, the FCAS was the only score not to differ significantly from the best performing model (including the number of injuries) in predicting the pain/discomfort outcome of the EQ-5D. As such, this study serves as a de facto validation of these summary scores.

Particular strengths of this study included the opt-off consent process and high follow-up rates recorded on the VSTR, and the inclusive trauma system which formed the setting for the study. A further strength is the inclusion of less severely injured orthopaedic trauma patients in addition to major trauma. Orthopaedic injuries have been found to account for the majority of years lived with disability among trauma patients admitted to hospital,[40] although many studies assessing trauma outcomes have focused on major trauma.[3–7 38] However, there were some limitations with the present study. Patients lost to follow-up differed from included cases in terms of gender, socioeconomic status, mechanism and intent of injury. As such, there may be biases which affect the interpretation of the study's findings. However, these are likely to be minor given the comparatively small associations between assessed functional outcomes and both the FCI and AIS.[12]

Dichotomisation of assessed outcomes is appropriate[32] and has been used for these outcomes.[25 27 28] However, it is possible that individual predictors may have greater or lesser effects at different levels of function. For example, gender may be poor at discriminating between GOS-E of 2 and 3, but effective at discriminating between GOS-E of 7 and 8. Similar effects may also be present across injuries of different types or to different body regions. However, the evaluation of subgroups of patients was outside the scope of the present study which sought to evaluate the overall performance of the FCI.

Similarly, AIS-based and FCI-based scores are known to be ordinal rather than continuous measures. However, ordinal logistic regression methods still assume a proportional variation between values. Given that this may not be the case, the techniques used were believed to be reasonable.

Other predictive factors such as education level, the presence of comorbidities and the compensability of a patient's injuries have been shown to predict both physical and psychosocial outcomes.[38] Model performance may have improved with the addition of these variables. However, the intent of the study was not to develop optimal models for outcome prediction but to assess the effects of different methods of categorising injury within such models.

CONCLUSION

Anatomical injury is a significant predictor of longer term functional, occupational and quality-of-life outcomes. Adding injury severity to a simple model improves the prediction of outcomes after serious injury. However, injury severity as described by the FCI does not consistently increase discrimination, or provide for the best discrimination, when compared with AIS-based severity scores or a simple count of the injuries sustained. In order to maximise their effectiveness, models predicting different aspects of physical or psychosocial recovery after severe trauma may require quite different representations of anatomical injury severity which may not be based on either AIS or FCI severities.

What is already known on the subject

- ► Recovery trajectories following serious injury vary widely, and existing injury severity measures based on AIS severity weightings account for only a small proportion of outcome variability.
- ► The revised predictive Functional Capacity Index (FCI) was developed to predict 12-month outcomes using the AIS code structure, but has not been thoroughly assessed and no summary scores for multiply-injured patients are available.

What this study adds

- ► Overall anatomical injury as measured by AIS-based or FCI-based scores or a simple injury count all contribute significantly, but only slightly to the prediction of a variety of 12-month physical and psychosocial outcomes including return to work.
- ► FCI-based scores do not consistently or substantially improve outcome predictions compared with other injury scores; as such, the FCI is unlikely to be fit for its intended purpose as a global functional outcome prediction tool. Prediction models may require injury scores which are specific to the outcome being assessed.

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6.3 SUMMARY

The purpose of the FCI was to enable the prediction of recovery or loss of function 12 months after injury for all blunt and penetrating trauma patients. Although the truncated FCI was able to significantly improve on outcome predictions made by a simple model of age and gender, in practical terms the improvements were small. More importantly, the FCI often did not perform better than the mortality-weighted AIS-based scores which the FCI was designed to supersede, and was outperformed on some outcome measures by both AIS-based scores and a simple count of injury codes assigned. As such, even if some uses for the FCI are found within subsets of the trauma population, the FCI is not fit for the purpose for which it was designed.

In a population of more than 20,000 major and orthopaedic trauma patients split for model development and testing, models using summary scores based on the FCI generally achieved marginally higher areas under the ROC curves than other injury scores for domains involving physical function, but did not perform as well with psychosocial and health-related quality of life domains. Calibration was reported as acceptable for all outcome measures apart for the GOS-E model. However, calibration was generally poorer at extremes; the FCI tended to give pessimistic estimates of function for the most debilitating injuries, but overestimated recovery for many patients with less severe (though still disabling) injuries.

These results lead to two important points. Firstly, when attempting to predict outcomes amongst survivors of trauma, there is presently no clearly superior method for summarising the individual or overall severity of injuries sustained. The methods trialled in the current study were a mixture of well-established scores such as the MAIS, ISS, NISS and worst FCI, and novel summary scores. However, although all of these scores have justifications for their use, they employ methods of grouping or transforming detail-rich AIS coding which are not empirically derived, and hence may be thought of as essentially arbitrary.

Secondly, measures such as the EQ-5D-3L describe psychosocial aspects of quality of life as well as physical function; the former are specifically excluded from the FCI's ten dimensions of function and this was reflected in the study results. Moreover, calibration indicated that the measures of injury severity employed did not perform consistently depending on the severity of the outcome being predicted. As such, the accurate prediction of recovery following injury is likely to require quite different tools for each domain of physical or psychosocial function after injury, and potentially for different levels of a given domain. In turn, each of these tools may require different expressions of injury severity.

A further important finding of this study was that for psychosocial aspects of function, neither the FCI nor the AIS provided the best method for describing injury severity within the models used. A simple count of the number of injuries sustained (albeit as represented by the number of AIS codes assigned) was able to outperform measures based on injury severities found in the 2008 AIS dictionary. As such, even if the structure of the AIS is retained, it is feasible that there may be better ways to describe the anatomical injuries sustained by patients in the context of predicting outcomes which are not related to physical recovery.

Chapter Seven
Conclusion

7.1 Discussion

7.1.1 Summary of Key Findings

This thesis aimed to develop and evaluate tools enabling better utilisation of AIS-coded datasets. The study described in Chapter Two developed a new tool - a map between the 1990 and 1998 versions of the AIS. Because of the prior development of mapping tools between the 1998 and 2008 AIS,[134,135] this study enabled data coded using any currently used AIS version to be evaluated using the most contemporary AIS lexicon (AIS 2008). Similarly, the study reported in Chapter Three considered the importance of AIS summary scores such as the ISS and NISS, and re-evaluated how such scores might be better used in order to maintain consistency in how severe trauma is defined in the setting of the 2008 AIS. These studies addressed the first of the more specific research aims, in that AIS datasets and their derived summary scores may be used in ways which are comparable over time and between jurisdictions.

The second research aspect of this thesis explored the use of the FCI as a potential method for using AIS-coded data to predict outcomes other than mortality. The studies described in Chapters Five and Six implemented the recommendations made by the literature review performed in Chapter Four, by progressively evaluating the performance of the FCI in its predictions of 12-month outcomes following severe trauma. This included the development of summary scores using FCI severities, although these were unable to add substantially more information to 12-month outcome predictions than AIS-based scores. This represents an important negative finding.

Through all of the above work, a number of principles - concepts regarding how changes in the AIS may be assessed and adjusted for, or how the AIS could best be used to describe injury in a population - which may affect the direction of future AIS-related research were identified. This was a second aspect of the overall aim of this thesis. Prior to making recommendations and conclusions for this thesis, this chapter will explore some of these concepts with reference to preceding chapters.

7.1.2 Adapting to AIS Codeset Change

The AIS lexicon requires periodic updating in order to reflect concurrent changes in the diagnosis, treatment and prognosis of particular injuries. Such changes are likely to occur gradually in clinical practice. However, changes to the AIS codeset occur only once or twice per decade. From a registry perspective, if appropriate adjustments for the adoption of a new AIS version are not made, this may result in sudden and quite substantial changes to assessed injury severity. The study reported in Chapter Two noted that individual revisions of the AIS codeset often involve substantial change to particular body regions or structures.[124,129,133] As a result, variability in the performance of the AIS in predicting any outcome may be due not only to the incidence of particular injuries (as represented by AIS codes) in a given dataset,[39] but also to the version of the AIS used.

An AIS map which complemented existing AIS mapping tools[40,134,135] was developed and described in Chapter Two. Changes in calculated ISS were described, and only a small proportion of patients had a change in calculated ISS; as a result, the impact on major trauma classification (less than 1%) was minimal. The net result of this study is the completion of an AIS mapping system, enabling the conversion of AIS codes in existing trauma registry datasets to the most current (2008) version. This system was developed over a number of years, and necessitated the development of methods to evaluate and compare AIS codesets in addition to the maps themselves.

However, the currency of these mapping tools is already threatened, as a new AIS version was released in 2015.[168] At the time of completing this thesis in early 2019, however, the 2015 AIS does not appear to have been adopted (or at least reported on) by any trauma registries.[169] Moreover, only two papers have cited the 2015 AIS. The first was a brief communication by the AAAM at the time of its release.[170] The second paper reviewed the content, and some history of the development of more recent AIS versions, without evaluating the effects of adopting or switching between any versions (including the 2015 AIS) on patient data.[171] As such, the findings of the first half of this thesis remain particularly relevant to the 2015 AIS in that (along with the research listed in Appendix One) they provide several principles enabling the complete assessment of this revised version. These are summarised in the Recommendations section later in this Chapter.

The ability of the trauma 'community' - the broad groups of clinical and non-clinical specialists concerned with trauma management and outcomes - to satisfactorily adopt a new AIS version is largely dependent on the effect of that version on derived injury scores. The study reported in Chapter Three advocated a return to the concept of objective external comparisons (such as a target mortality rate) in order to standardise how the ISS is used across AIS versions. Although mortality rates varied substantially across different values of the ISS, this study found that using an ISS >12 threshold with the 2008 AIS returned similar ISS performance to that using an ISS >15 with the older 1998 AIS. Although targets may vary over time, they at least provide an external basis for the validation of AIS-based score cut-offs used. This study also found that the use of other (non-AIS) criteria such as death or resuscitative needs can moderate the size of any change in major trauma classification arising from AIS version change.

However, the research described in Chapter Three also stressed that the use of an updated ISS threshold for identifying major trauma patients should be regarded as a ‘stop-gap’ measure, for two reasons. Firstly, as explored in the second half of this thesis there is a recognised need to measure non-fatal outcomes amongst trauma survivors. Secondly, even where mortality remains the outcome of interest, the simple ISS is most likely not the best method for using AIS data to describe the overall severity of a patient's injuries.

7.1.3 Limitations – and Potential - of the AIS and ISS

As noted in Chapter One, the ISS - and the AIS from which it is derived - has many limitations. However, at the time of its development no other summary scores were available. The ISS was simple to calculate, and the rationale for the construction of the ISS was acceptable. Also, although most were methodologically flawed, several early validation studies found that the ISS was associated with outcomes as diverse as mortality,[31,32,56,57] disability,[56] the need for surgery,[32] length of hospital stay [32,56] and even trauma incidence [32] and the quality of trauma care.[33] Widespread adoption of the ISS was consequently inevitable. However, the ISS was developed more than 40 years ago, for use with an AIS version which (although conceptually similar) bears virtually no relationship to contemporary AIS versions.

In this context, two particular limitations of the AIS deserve comment. The first is the variability in mortality risk - particularly between body regions - across the AIS codeset for injuries of a given severity level.[66,77,172,173] In noting this flaw in the performance of the derived ISS, some alternative scores have evaluated and regrouped AIS codes into different body regions,[44,45] while others have ignored body regions altogether.[42,43,46] Nevertheless, the ISS remains embedded in contemporary thinking around how the AIS is used to describe trauma severity in a population.[60] It was discussed in Chapter Three that persistent use of the ISS forms a barrier to the adoption of newer and better scores. However, even alternative AIS-based summary scores still utilise underlying AIS codes, with any inherent flaws.

The AIS has evolved to maintain currency with diagnostic and treatment capabilities. Although such development of the codeset is therefore desirable, it has resulted in more recent AIS versions being both large and highly complex; the 2008 AIS contains 1,999 codes which may be assigned to the injuries sustained by each patient. This forms a second limitation of the AIS - and one which is acknowledged as such by the AAAM[17] – for two reasons. AIS coding - and hence derived scores - may not be reliable with large AIS codesets;[65,174-177] this is likely to be worse if the AIS codeset increases further. Also, many AIS codes are rarely or never assigned, even in large datasets.[39,47,178,179] In some settings, alternative or reduced AIS codesets have been developed and used,[86,179] or analyses have been restricted to more frequently occurring AIS codes.[178] However, this limits the comparability of patient data across registries or jurisdictions, even if it has nominally been coded using the same AIS version.

The study reported in Chapter Three attempted to compare AIS summary scores derived from different AIS versions using objective and independent measures of 'severity'; even so, the conclusion of this study was that methods of better using the AIS lexicon should be developed. Such methods could conceivably use the existing AIS codes (and assigned severities) in more complex ways, or re-assess the assigned severities themselves. As discussed in Chapter One, the severity levels assigned to individual AIS codes are weighted towards mortality risk; the FCI was later developed as it was identified that AIS severities were not closely associated with the level of function or impairment amongst survivors of injury events. However, the actual dimensions of severity which are reflected in AIS severities may vary between codes, body regions or AIS versions.

Recognising this issue, a number of attempts have been made to develop alternate severities for AIS codes which are more explicitly evidence-based.[47,75,81,178,180] Although the methodology used to derive such estimates has varied, in principle these are similar to older systems (and some more recent systems) which utilised ICD codes to derive injury-specific likelihoods of survival or mortality.[75,181-189] These likelihoods have been termed survival risk ratios (SRRs),[186] or their complementary term, mortality risk ratios (MRRs).[178] When applied to the AIS, such measures are by definition specific to the structure and codeset of the AIS version being used. Additionally, though, they are specific to the population in which they were developed, both in terms of the epidemiology of trauma and the way in which the local systems manage injured patients.[35,190] As a result, it has been suggested that they may not actually be independent measures of injury severity.[190]

Measures based on SRRs are considerably more complex than global AIS summary scores such as the ISS and NISS. Given the history of the usage of injury severity scores, this is likely to preclude their use in many of the trauma system-related applications for which scores such as the ISS are currently used. However, they can be applied retrospectively to existing datasets. As such, trauma registries would not need to change current data collection and coding practices in order to utilise these tools.

7.1.4 The FCI - Conceptual Limitations

The FCI was designed to provide explicitly comparable predictions of the likely functional level of surviving trauma patients. The studies described in Chapters Five and Six demonstrated that the FCI did not agree closely with assessed 12-month outcomes, and added only marginally to the performance of models containing age and gender. On the basis of this research, then, the FCI has failed.

The methodology used to construct the FCI was questioned in both Chapter Four (regarding the multi-stage process used) and Chapter Five (regarding the lack of evidence for the four assumptions made by the FCI). Much of the development process for the revised FCI remains undocumented. The standard gamble approach believed to have been used to assign level weights and severities to each injury code is generally valid; however, the assessments of likely 12-month outcome for each single injury were still based on expert panel opinion. In the context of these issues, the 1966 report *Accidental Death and Disability: The Neglected Disease of Modern Society* [104] referred to in Chapter One remains relevant despite preceding the FCI by nearly 30 years. In considering convalescence and disability, the report provided the following anecdote:

> *"At a meeting of a local Committee on Trauma of the American College of Surgeons, a theoretical problem was presented to approximately 50 distinguished surgeons as to when a young man should resume heavy labor following specific injury. The estimates of duration of disability ranged from 2 weeks to a year, with little concentration of the estimates in between. There is little scientific basis on which to predict or measure convalescence or disability."* [104]

The FCI was developed based on the premise that outcomes from severe injury are largely attributable to the level of recovery from the anatomical injuries sustained:

> *"With increasing attention focused... on the design and evaluation of countermeasures that reduce the total long-term societal impact of injuries, there is a need to develop more effective measures that adequately quantify the individual and societal consequences of nonfatal injuries. The objective of this study was to develop such a measure."* [157]

It was consequently assumed that a tool such as the FCI would be used to risk-adjust for function - although this was itself only vaguely defined - in evaluating the effects of other factors affecting functional outcomes such as return to work. However, this is not the case.

The FCI was first developed during the mid-1990s,[157] prior to the first studies evaluating outcomes following severe or lower extremity injury.[191-196] These studies established that poor or delayed recovery were prevalent amongst survivors of severe injury, but only one commented on the influence of another factor (age) on recovery.[194] Evaluation of the contribution of factors other than anatomical injury to recovery and function only commenced around 20 years ago with the work of Holbrook and colleagues in the United States.[197-203] The developers of the FCI suggested that the FCI might be used to risk-adjust for function in evaluating the possible effect of other 'socio-demographic characteristics' on outcomes such as return to work.[157] However, it is now recognised - and to a certain extent was demonstrated in the findings of Chapter Six - that depending on the nature of the injuries sustained, anatomical injury may not always be a substantial contributory factor to outcomes following injury.[204] Additionally, depending on the outcome of interest the principal anatomical drivers of outcome may be limited to injuries sustained in particular body regions, rather than overall severity.[204] As such, the premise behind the development of the FCI appears to be flawed.

The FCI may be described as a prognostic tool for 12-month function after injury, based solely on coded descriptions of anatomical injury. Because injury itself is only partly predictive of functional outcome, scores which are able to successfully predict function are likely to be based on multivariate models. These may include age and gender as used in Chapter Six, as well as pre-injury socio-economic factors and comorbidities, the mechanism of injury and compensability. Within such models, though, the question of how best to quantify injury severity remains. Across a range of outcome measures, the study performed in Chapter Six demonstrated (in effect) that the optimal method for utilising the AIS structure to predict each outcome most likely remains unknown. Put another way, for a given patient or population the actual proportion of any given outcome that *is* attributable to anatomical injury - as measured imperfectly by the AIS and FCI - is unclear. Consequently, in attempting to predict functional loss or limitation following injury it is reasonable to explore alternate methods for determining 'severity' which are able to use the AIS codeset that is familiar to - and already collected by - existing trauma registries.

7.1.5 Future Outcomes Scoring

The study reported in Chapter Six concluded that quite different measures - and hence different uses of injury coding - may be required to improve the predictions of different functional outcomes following injury. Specific issues which could benefit from such measures include:

› benchmarking functional outcomes between populations or over time;

› developing disability-based 'casemix' funding for rehabilitation;

› determining the need for, or likelihood of requiring additional inpatient or post-discharge services such as pain management or mental health;

› determining the likely success of a rehabilitation program; or

› determining the likelihood of an individual returning to work within a given timeframe, or to a particular role.

The methods for utilising AIS and FCI severities which were employed by this study were fairly simple uses of AIS codes. However, there are already several published techniques for more closely evaluating detailed AIS coding in describing injury severity. Scores developed for mortality prediction have already used alternate injury region groupings[44,45] or different emphases on injuries regarded as more or less severe.[43] More recently, Schoell and colleagues have published several papers [205-208] exploring disability risk - a concept not dissimilar to SRRs and MRRs - as a data-driven alternative to severities such as those in the FCI. Such techniques might be useful in the future development and evaluation of outcome-specific tools.

Finally, the review in Chapter Four noted the variations seen in the accuracy of the FCI's predictions between different body regions. This may reflect problems with the specificity of the AIS on whose structure the FCI hangs, rather than the FCI's predictions per se. In turn, AIS classifications of severity depend on the quality and type of information regarding anatomical tissue damage which is available for coding purposes. In Chapter One, the example of the advent of CT and MRI providing additional information regarding the type and extent of epidural haematomas was presented; over time, such developments provided for gradually increasing specificity in AIS coding for this type of injury. In the same way, the review in Chapter Four highlighted the example of soft tissue cervical spine ('whiplash') injuries, and their potential effects on the accuracy of the FCI. These injuries frequently do not require acute hospital admission and are unlikely to result in long-term impairment, but in some settings account for a large proportion of patients suffering impairment. Further diagnostic advances may be better able to differentiate between whiplash injuries which are or are not likely to have ongoing effects; consequently, future versions of the AIS may better be able to categorise these.

7.1.6 Strengths and Limitations of Presented Research

There were two key strengths to the research presented in this thesis. Firstly, the studies undertaken were able to identify and complete a number of small, key gaps in existing research which had been identified by previous research (see Appendix One) and the literature review presented in Chapter Four. Chapter Two comprised a study which completed the suite of mapping tools necessary to enable the comparison of AIS-coded datasets using any currently-used AIS version, while the work presented in Chapter Three provided continuity across these versions in the classification of severely injured patients using the ISS. Studies reported in Chapters Five and Six progressively investigated the FCI based on the work presented in Chapter Four and (in the case of Chapter Six) Chapter Five.

Four of the five studies reported in this thesis (the exception being the narrative review) used one of three trauma registry datasets. The Victorian State Trauma Registry (VSTR) used in three studies captures data within an inclusive trauma system, providing complete population coverage of major trauma, and employing an opt-off consent process enabling high follow-up rates of over 80% at 12 months. The orthopaedic minor trauma patients included in the dataset for Chapter Six also enabled follow-up of not only the most severely injured patients in the Victorian State Trauma System, but also those most likely accounting for much of the disability burden amongst hospital-admitted patients. The Queensland Trauma Registry (QTR) used in Chapter Two was not a population-based registry, although the use of triage networks within the state at that time resulted in an estimated 90% population capture for serious injury. As such, the datasets used are robust and provide a second strength underpinning the presented research.

However, there may be limitations which affect the transferability of this research. This thesis only used data from Australian patients. Several factors may contribute to a unique profile for the epidemiology and management of trauma in Australia. Australia enjoys a relatively low mortality from motor vehicle trauma, and has a comparatively low incidence of penetrating trauma. In particular, gun violence is uncommon in Australia due to strong legislative controls on particular firearm types and gun ownership. Australian patients benefit from a well-established universal healthcare system, and mature state-wide or regional trauma systems in several Australian states also provide for further improvements in care and outcomes. As such, differences between Australian patients and those in other jurisdictions may exist, and this may affect the generalisability of study findings.

Although the VSTR and QTR have a high population capture, there were likely biases in their coverage of severe injury. The small proportion of patients missed by the QTR in Chapter Two (as they were triaged to, or presented to and retained by smaller hospitals not contributing to the QTR) may have differed in epidemiology, injuries and outcome from captured patients. In the case of the VSTR, patients who die prior to arrival at hospital are identified using coronial data, but are not captured at patient-level.

The previous section noted that a substantial proportion of patients with ongoing functional loss after injury may have only sustained comparatively minor (by AIS severity) injuries. The findings reported in Chapters Five and Six utilised the VSTR and VOTOR (Victorian Orthopaedic Trauma Outcomes Registry) registries, and hence may have been biased towards patients who sustained injuries with high AIS and low FCI, and away from (for example) lower leg or 'whiplash' injuries. Due to the inclusion of patients co-enrolled on VOTOR in Chapter Six, there was a known weighting towards orthopaedic trauma patients. In this dataset, it was noted that patients who were lost to follow-up at 12 months were as a group younger and more socioeconomically disadvantaged, and had a higher incidence of penetrating trauma than the patients who were used to evaluate the FCI; they were also more likely to have sustained only injuries predicted to recover well.

The evaluation of AIS-derived scores' ability to predict functional outcomes was limited to assessments of function made 12 months following injury. This time point was evaluated specifically as it was the same as that predicted by the FCI. There is evidence that recovery of function continues beyond 12 months, although such recovery is dependent on several different factors and recovery trajectories can be complex.[145,204,209] As such, the findings reported in Chapters Five and Six may not be directly applicable to other time points following injury.

This thesis developed and evaluated tools which are specific to the use of the AIS for classifying injury, and did not consider ICD-based tools. The AIS is comparatively expensive to use as it requires disease-specific coding for injured patients, while ICD coding is performed routinely on hospitalised patients worldwide. However, there were several reasons (many discussed in Chapter One) for limiting this thesis to AIS-based measures. Firstly, AIS-based measures underpin many aspects of trauma systems. Secondly, the AIS provides a lexicon which is (by definition) focused on the classification of injury, and aims to do so in a manner which is explicitly comparative (via both AIS and FCI severities). Thirdly, this comparative nomenclature, in spite of its limitations, allows for the direct calculation of simple summary scores which have been widely adopted. Fourthly, ICD codes are assigned to hospital-admitted patients and are limited in their scope where patients may die or be treated outside of hospitals.[35] Fifthly, ICD-based tools are data-driven - their discussion earlier in this chapter notwithstanding, such measures are not independent from the outcomes being assessed.[190] Finally, there were several specific areas where issues with the contemporary use of AIS-based coding and scoring had been identified; these were compatible with the aims of, and quantity of research required for this thesis.

7.2 Key Findings and Recommendations

The overall aim of this thesis was to evaluate and develop validated tools for the use and interpretation of injury data coded using the most current AIS version, and to identify and develop principles for severity assessment which are likely to remain valid for future revisions of the AIS. In relation to this aim, the key findings - and the recommendations which follow these - are presented.

I. New AIS versions require considerable evaluation in order to maintain consistency in how injury severity is described.

The findings of the research in Chapter Two added to a previous body of work demonstrating the feasibility of changing the AIS version which is used by an established data collection. This requires several steps. Firstly, a code-level comparison of the two versions must be performed. This involves identifying injuries within particular body regions, or particular injury types which may be affected more by the AIS version change. Because some AIS codes occur frequently and others rarely or not at all, a second step is the assessment of variations in the incidence of AIS codes to determine the actual, rather than theoretical changes in injury severity across a dataset. A third, integral component of changing between two AIS versions is then the development of, or (if maps have been provided in the AIS dictionary) the checking of maps.

Recommendation: The structure and severity levels inherent in the 2015 or future AIS versions must be evaluated to ascertain the effects of adopting this new version on existing data collections. In order to do so completely, the above steps should be followed.

II. The adoption of new AIS versions affects AIS-based summary scores and patient classification.

Once the changes in AIS severity and across body regions within a population are known, the effects of AIS version change on calculated scores can then be assessed. The research in Chapter Three re-evaluated the use of AIS-based scores in classifying severely injured patients. Although outdated, scores such as the ISS and NISS continue to play integral roles in the structure and monitoring of modern trauma systems. Terms such as major trauma or 'polytrauma' are used to identify key groups within trauma populations. However, in order to maintain consistency across AIS version changes, it is essential that these terms should be linked to empirically measurable standards, such as - as used in the past - a target mortality rate.

Recommendation: The effects of adopting the 2015 or future AIS versions on the widely-used ISS and NISS should be quantified, along with the secondary effects on various patient classifications including major trauma. Recalibration of such terms should occur with each AIS version, and should be linked to objective measures.

Recommendation: The adoption of newer and more accurate scores in place of the ISS or NISS for mortality prediction should be strongly encouraged.

III. There is no clearly superior method for utilising the AIS codeset to predict functional outcomes in survivors of trauma.

The FCI is not fit for the purpose for which it was developed - namely, to provide global assessments of likely patient function 12 months following injury. The study described in Chapter Five found that FCI severities were superior to AIS severities across the whole range of function covered by the GOS-E. However, the subsequent study reported in Chapter Six identified that across many different types of function - including psychosocial function and practical outcomes such as return to work - the performance of AIS and FCI were similar, and a severity-independent measure was capable of outperforming both. Moreover, none of the methods used to describe injury severity accounted for more than a fraction of the variability in any of the outcomes measured, and the contribution of the other variables used also varied. As such, variations in the factors predicting each outcome - and in the amount of variability explained by each factor - necessitate the separate consideration of each outcome of interest.

Recommendation: Specific, measurable outcomes following injury should be identified; multivariable prognostic tools should be developed separately for each outcome. Consideration should be given as to how injury severity can best be represented within each tool; a variety of methods are available.

Recommendation: Further exploration of ways to most appropriately utilise the detail inherent in AIS coding across a variety of outcomes should be encouraged.

IV. There is little evidence for the assignment of AIS or FCI severities.

The consensus-based methods used to assign AIS and (at least in part) FCI severities has been discussed in Chapter One, and Chapters Four through Six. In addition to the ongoing use of expert opinion to assign severities to AIS codes, the review in Chapter Four highlighted the paucity of available information regarding the severity weightings or specific methodology used in the construction of the revised FCI, as well as the lack of an evidence base for the four assumptions on which the FCI's severities rested. This chapter has described alternate methods which could be used to create evidence-based severities for use with the AIS codeset. The utility of such severities would be reliant (at least in part) on the peculiarities of the dataset used to derive them.

Recommendation: The rationale behind the selection of severity levels assigned by the AAAM to the AIS, FCI or any other severities should be made explicit, and where possible consistent across the AIS lexicon. Where possible, the assignment of severity levels to codes in future AIS versions should be evidence-based, if not data-driven.

7.3 Concluding Remarks

Trauma is a significant public health issue. For half a century, the Abbreviated Injury Scale has provided the structure and nomenclature used to classify, describe and compare injured patients and populations. In doing so, the AIS has underpinned many of the ways in which societies have driven reductions in trauma mortality and improvements in patient care through the development of trauma systems.

This thesis aimed to evaluate and develop validated tools for use with the AIS, and to identify and develop principles which would enable the ongoing relevancy of the AIS, and the uses to which it is put. The research described in this thesis has identified that maintaining currency in terms of AIS-derived severity assessments is feasible. Such currency requires periodic review of the AIS lexicon by its developers. Additionally, though, discussion and research within the trauma community which both uses and relies upon the AIS are required to determine how each AIS version might best be used to describe the severity of injury in terms which are informative of outcomes of interest.

It is hoped that this research will equip clinicians, researchers and registry custodians with the tools to evaluate the burden of trauma using contemporary terminology. Beyond this, it is also hoped that this research will promote wider recognition of the issues surrounding AIS-based injury classification. These include the subjectivity of AIS and FCI severities, and the complexities of using these in attempting to better assess and predict a range of outcomes following trauma. Given that large AIS-based data collections already exist worldwide, alternative ways of using the extraordinarily rich, injury-specific detail contained in AIS coding to better effect in assessing severity and predicting outcomes should be explored.

Classification and scoring systems used to assess the severity of disease must remain relevant. The epidemiology, diagnosis and management of injury will inevitably change over time. The outcomes following injury which are of interest, or how the quality of the care provided is assessed will similarly vary and diversify. Scoring systems such as the AIS must adapt to all of these changes, while maintaining comparability over time. Maintaining the relevancy of the AIS is a task not only for its developers, but also for those who use the AIS to assess, compare or drive improvements in patient care.

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Appendices

Appendix One
Additional Output Related to PhD Themes

2010

Palmer CS, Niggemeyer LE, Charman D. Double coding and mapping using Abbreviated Injury Scale 1998 and 2005: identifying issues for trauma data. Injury 2010 Sep; 41(9):948-954.

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Appendix Two
Other Research Output During Candidature

2011

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Appendix Three
Supplementary Data To Paper, Chapter Five

This supplementary data was referred to as Table S1 (supporting information) in the paper, 'Revised Functional Capacity Index as a predictor of outcome following injury' contained in Chapter Five. It is currently available online via the following link:

https://onlinelibrary.wiley.com/action/downloadSupplement?doi=10.1002%2Fbjs.10638&attachmentId=196769692

Assessment of the revised Functional Capacity Index as a predictor of 12 month outcomes following injury

Supplemental material

Sensitivity analysis around GOS-E categorisation

The Extended Glasgow Outcome Scale (GOS-E) was compared with the predictions from the Functional Capacity Index located within the 2008 Abbreviated Injury Scale (pFCI08). The seven GOS-E scores 2 through 8 (representing survival) may be collapsed into five categories in fifteen different ways. The GOS-E groupings used in this sensitivity analysis are shown below, along with weighted and unweighted levels of agreement between predictive (pFCI08) and actual (GOS-E) scores and bias-corrected 95% confidence intervals (CI).

	pFCI08 level (GOS-E scores corresponding to each pFCI08 category)					Kappa test results: Unweighted kappa		Kappa test results: Quadratic weighted kappa	
Grouping	1	2	3	4	5	*k* value	95% CI	*k* value	95% CI
Method 1	2, 3, 4	5	6	7	8	**0.078**	0.054, 0.099	**0.207**	0.164, 0.249
Method 2	2	3, 4, 5	6	7	8	**0.058**	0.039, 0.077	**0.186**	0.146, 0.223
Method 3	2	3	4, 5, 6	7	8	**0.056**	0.038, 0.076	**0.178**	0.137, 0.216
Method 4	2	3	4	5, 6, 7	8	**0.065**	0.045, 0.086	**0.186**	0.146, 0.228
Method 5	2	3	4	5	6, 7, 8	**0.091**	0.061, 0.118	**0.189**	0.150, 0.239
Method 6	2, 3	4, 5	6	7	8	**0.071**	0.051, 0.092	**0.200**	0.159, 0.240
Method 7	2, 3	4	5, 6	7	8	**0.070**	0.051, 0.093	**0.208**	0.165,0.253
Method 8	2, 3	4	5	6, 7	8	**0.076**	0.054, 0.099	**0.234**	0.190, 0.288
Method 9	2, 3	4	5	6	7, 8	**0.095**	0.066, 0.118	**0.244**	0.195, 0.294
Method 10	2	3, 4	5, 6	7	8	**0.058**	0.038, 0.076	**0.193**	0.151, 0.234
Method 11	2	3, 4	5	6, 7	8	**0.063**	0.040, 0.084	**0.219**	0.175, 0.262
Method 12	2	3, 4	5	6	7, 8	**0.080**	0.054, 0.105	**0.230**	0.183, 0.275
Method 13	2	3	4, 5	6, 7	8	**0.061**	0.042,0.082	**0.203**	0.162, 0.243
Method 14	2	3	4, 5	6	7, 8	**0.078**	0.052, 0.104	**0.215**	0.172, 0.258
Method 15	2	3	4	5, 6	7, 8	**0.082**	0.055, 0.105	**0.200**	0.158, 0.237

Key: ***Best-performing grouping for weighted GOS-E - pFCI08 comparison*** (shaded: Method 9)

APPENDIX FOUR
SUPPLEMENTARY DOCUMENTS TO PAPER, CHAPTER SIX

These three supplementary documents were referred to as Supplement 1 through Supplement 3 in the paper, 'Comparison of revised Functional Capacity Index scores with Abbreviated Injury Scale 2008 scores in predicting 12-month severe trauma outcomes' contained in Chapter Six. In addition to explanatory notes, these documents contain supplementary tables eTable 1, eTable 2, eTable 3 and eTable 4.

These documents are formatted for submission to the journal Injury Prevention, but are not yet available online.

Comparison of revised Functional Capacity Index scores with Abbreviated Injury Scale 2008 scores in predicting 12-month severe trauma outcomes

CS Palmer, PA Cameron, BJ Gabbe

Supplement 1
AIS codes not used in analysis

Contents

Introduction

This supplement contains two tables. The first (eTable 1) lists the 52 AIS codes for blunt or penetrating injury which do not have an assigned FCI severity. A total of 28 793 adult patients (see main paper, Figure 1) were included in this study; these patients sustained a total of 148 136 injuries as coded using AIS, of which 525 (0.3%) did not have an FCI severity. Also shown in eTable 1 are the number of these injuries sustained amongst the 20 813 patients used for analysis; these patients sustained a total of 111 245 injuries as coded using AIS, of which 334 (0.3%) did not have an FCI severity. However, these patients also sustained additional injuries which provided meaningful AIS and FCI severities, and hence were included in the analysis.

The second table (eTable 2) lists the 90 AIS codes describing superficial injuries assigned both AIS 1 and FCI 5 severities. A total of 24 693 AIS codes were assigned to these injuries amongst the 28 793 patients included in the study; this represented 17% of the 148 136 AIS codes assigned to these patients. Amongst the 111 245 AIS codes assigned to the 20 813 patients used in the analysis, 18 356 (17%) were assigned one of the below 90 AIS codes.

eTable 1. AIS 2008 codes for blunt/penetrating injury with no associated 2008 FCI scores.

AIS code [1]	Injury description [1] *	Incidence (28 793 study patients)	Incidence (20 813 analysis patients)
100099.9	Injuries to the Head NFS	12	1
100999.9	Injuries to the Head - Died without further substantiation of injuries	16	0
121602.4	Artery - Other branch of anterior, posterior or middle cerebral - laceration	5	4
121604.3	Artery - Other branch of anterior, posterior or middle cerebral - thrombosis; occlusion	1	0
121606.3	Artery - Other branch of anterior, posterior or middle cerebral - traumatic aneurysm	3	1
121699.3	Artery - Other branch of anterior, posterior or middle cerebral - NFS	3	2
140489.9	Cerebellum - trauma-associated findings not related either to intervention	0	0
140681.3	Ischemic cerebrum damage directly related to head trauma - no coma >6 hours	0	0
140683.5	Ischemic cerebrum damage directly related to head trauma - coma >6 hours	4	0
140689.9	Cerebrum - trauma-associated findings not related to intervention or anatomical injury	0	0
200099.9	Injuries to the Face NFS	5	1
200999.9	Injuries to the Face - Died without further substantiation of injuries or no autopsy	1	0
220099.9	Vascular Injury in Face NFS	0	0
300099.9	Injuries to the Neck NFS	0	0
300999.9	Injuries to the Neck - Died without further substantiation of injuries or no autopsy	0	0
320099.9	Vascular Injury in Neck NFS	1	0
400099.9	Injuries to the Whole Thorax NFS	1	0
400999.9	Injuries to the Whole Thorax - Died without further substantiation of injuries or no autopsy	3	0
420099.9	Vascular Injury in Thorax NFS	1	1
440099.9	Bronchus injury NFS	0	0
442999.9	Thoracic injury NFS	1	0
450289.1	Rib Cage - contusion	6	4
500099.9	Injuries to the Whole Abdomen NFS	6	1
500999.9	Injuries to the Whole Abdomen - Died without further substantiation of injuries or autopsy	6	0
520099.9	Vascular Injury in Abdomen NFS	3	2
600099.9	Injuries to the Cervical Spine NFS	6	3
600999.9	Injuries to the Cervical Spine - Died without further substantiation of injuries	1	0

AIS code [1]	Injury description [1] *	Incidence (28 793 study patients)	Incidence (20 813 analysis patients)
620099.9	Injuries to the Thoracic Spine NFS	0	0
620999.9	Injuries to the Thoracic Spine - Died without further substantiation of injuries	0	0
630099.9	Injuries to the Lumbar Spine NFS	2	2
630999.9	Injuries to the Lumbar Spine - Died without further substantiation of injuries	0	0
650205.3	Cervical disc injury - rupture	20	15
650405.3	Thoracic disc injury - rupture	11	9
650605.3	Lumbar disc injury - rupture	3	3
700099.9	Injuries to the Whole Upper Extremity NFS	5	4
700999.9	Injuries to the Whole Upper Extremity - Died without further substantiation of injuries	0	0
712000.2	Compartment syndrome from soft tissue trauma, not fracture or destruction NFS	6	5
740099.9	Upper extremity - Muscle, tendon or ligament injury NFS	24	18
750099.9	Upper Extremity fracture NFS	0	0
770099.9	Upper extremity joint injury NFS	1	1
800099.9	Injuries to the Whole Lower Extremity NFS	2	2
800999.9	Injuries to the Whole Lower Extremity - Died without further substantiation of injuries	3	0
820099.9	Vascular Injury in Lower Extremity NFS	1	1
830099.9	Nerve injury in lower extremity NFS	3	1
840099.9	Lower extremity - Muscle, tendon, ligament injury NFS	26	21
840602.1	Muscle tear; avulsion - contusion; strain	22	15
850099.9	Lower Extremity fracture NFS	1	0
856163.4	Pelvic ring fracture, incomplete disruption posterior arch - blood loss ≤ 20%	114	91
856164.5	Pelvic ring fracture, incomplete disruption posterior arch - blood loss > 20%	54	33
856172.4	Pelvic ring fracture, complete disruption posterior arch & pelvic floor - blood loss ≤ 20%	58	42
856173.5	Pelvic ring fracture, complete disruption posterior arch & pelvic floor - blood loss > 20%	84	51
870099.9	Lower extremity joint injury NFS	0	0

* NFS - Not Further Specified.

1. Adapted from Gennarelli TA, Wodzin E, eds. *Abbreviated Injury Scale 2005 - Update 2008.* Barrington, IL: AAAM; 2008.

eTable 2. AIS 2008 codes representing minor superficial injury (AIS level 1 and FCI level 5).

AIS code [1]	Injury description [1] *	Incidence (28 793 study patients)	Incidence (20 813 analysis patients)
1100991	Scalp NFS	0	0
1102021	Scalp - abrasion	368	279
1104021	Scalp - contusion; subgaleal hematoma if >6 months old	2790	1976
1106001	Scalp - laceration NFS	605	409
1106021	Scalp - laceration - minor; superficial	1966	1432
1108001	Scalp - avulsion NFS	4	4
1108021	Scalp - avulsion - superficial; minor; tissue loss ≤100cm^2	19	13
2100991	Face - Skin/subcutaneous/muscle NFS	4	1
2102021	Face - Skin/subcutaneous/muscle - abrasion	1013	768
2104021	Face - Skin/subcutaneous/muscle - contusion; hematoma	2073	1470
2106001	Face - Skin/subcutaneous/muscle - laceration NFS	682	511
2106021	Face - Skin/subcutaneous/muscle - laceration - minor; superficial	2627	1970
2108001	Face - Skin/subcutaneous/muscle - avulsion NFS	5	5
2108021	Face - Skin/subcutaneous/muscle - avulsion - minor; superficial; ≤25cm^2	37	34
2160001	Face - Penetrating injury NFS	3	1
2160021	Face - Penetrating injury - minor; superficial	16	12
3100991	Skin/subcutaneous tissue/muscle NFS	4	2
3102021	Skin/subcutaneous tissue/muscle - abrasion	73	58
3104021	Skin/subcutaneous tissue/muscle - contusion; hematoma	204	167
3106001	Skin/subcutaneous tissue/muscle - laceration NFS	21	14
3106021	Skin/subcutaneous tissue/muscle - laceration - minor; superficial	59	40
3108001	Skin/subcutaneous tissue/muscle - avulsion NFS	2	1
3108021	Skin/subcutaneous tissue/muscle - avulsion - minor; superficial; ≤25cm^2	0	0
3160001	Neck - Penetrating injury NFS	3	1
3160021	Neck - Penetrating injury - minor; superficial	31	23
4100991	Skin/subcutaneous/muscle NFS	2	2
4102021	Skin/subcutaneous/muscle - abrasion	297	226

AIS code [1]	Injury description [1] *	Incidence (28 793 study patients)	Incidence (20 813 analysis patients)
4104021	Skin/subcutaneous/muscle - contusion; hematoma	561	421
4106001	Skin/subcutaneous/muscle - laceration NFS	12	9
4106021	Skin/subcutaneous/muscle - laceration - minor; superficial	71	48
4108001	Skin/subcutaneous/muscle - avulsion NFS	2	2
4108021	Skin/subcutaneous/muscle - avulsion - minor; superficial	2	1
4160001	Chest - Penetrating injury NFS	11	7
5100991	Skin/Subcutaneous/Muscle [except rectus abdominus] NFS	6	6
5102021	Skin/Subcutaneous/Muscle [except rectus abdominus] - abrasion	374	297
5104021	Skin/Subcutaneous/Muscle [except rectus abdominus] - contusion; hematoma	972	764
5106001	Skin/Subcutaneous/Muscle [except rectus abdominus] - laceration NFS	34	29
5106021	Skin/Subcutaneous/Muscle [except rectus abdominus] - laceration - minor; superficial	87	63
5108001	Skin/Subcutaneous/Muscle [except rectus abdominus] - avulsion NFS	12	10
5108021	Skin/Subcutaneous/Muscle [except rectus abdominus] - avulsion - minor; superficial	5	4
5160001	Abdomen - Penetrating injury NFS	6	2
7100991	Skin/subcutaneous/muscle NFS	6	4
7102021	Skin/subcutaneous/muscle - abrasion	1527	1195
7104021	Skin/subcutaneous/muscle - contusion; hematoma	804	579
7106001	Skin/subcutaneous/muscle - laceration NFS	391	265
7106021	Skin/subcutaneous/muscle - laceration - minor; superficial	1264	958
7108001	Skin/subcutaneous/muscle - avulsion NFS	10	5
7108021	Skin/subcutaneous/muscle - avulsion - minor; superficial	11	9
7160001	Penetrating injury in Upper Extremity NFS	4	3
7160021	Penetrating injury in Upper Extremity - superficial; minor	28	19
7160101	Penetrating injury at shoulder NFS	1	1
7160111	Penetrating injury at shoulder - superficial; minor	2	0
7160141	Penetrating injury at or above elbow, below shoulder NFS	1	0
7160151	Penetrating injury at or above elbow, below shoulder - superficial; minor	13	9
7160181	Penetrating injury below elbow, at or above wrist NFS	3	2
7160191	Penetrating injury below elbow, at or above wrist - superficial; minor	9	7

AIS code [1]	Injury description [1] *	Incidence (28 793 study patients)	Incidence (20 813 analysis patients)
7160221	Penetrating injury hand, partial or complete NFS	2	1
7160231	Penetrating injury hand, partial or complete - superficial; minor	1	0
7160261	Penetrating injury thumb NFS	1	1
7160271	Penetrating injury thumb - superficial; minor	0	0
7160301	Penetrating injury non-thumb finger NFS	3	1
7160311	Penetrating injury non-thumb finger - superficial; minor	0	0
8100991	Skin/subcutaneous/muscle NFS	10	7
8102021	Skin/subcutaneous/muscle - abrasion	1669	1328
8104021	Skin/subcutaneous/muscle - contusion; hematoma	1101	816
8106001	Skin/subcutaneous/muscle - laceration NFS	230	166
8106021	Skin/subcutaneous/muscle - laceration - minor; superficial	1000	781
8108001	Skin/subcutaneous/muscle - avulsion NFS	9	8
8108021	Skin/subcutaneous/muscle - avulsion - superficial; minor	17	12
8160001	Penetrating injury in Lower Extremity NFS	10	9
8160021	Penetrating injury in Lower Extremity - superficial; minor	34	27
8160101	Penetrating injury at hip or buttock NFS	2	2
8160111	Penetrating injury at hip or buttock - superficial; minor	5	2
8160141	Penetrating injury at or above knee, below hip NFS	11	7
8160151	Penetrating injury at or above knee, below hip - superficial; minor	32	22
8160181	Penetrating injury below knee, at or above ankle NFS	2	1
8160191	Penetrating injury below knee, at or above ankle - superficial; minor	4	3
8160221	Penetrating injury foot, partial or complete NFS	0	0
8160231	Penetrating injury foot, partial or complete - superficial; minor	2	1
8160261	Penetrating injury great toe NFS	0	0
8160271	Penetrating injury great toe - superficial; minor	0	0
8160301	Penetrating injury toe, single or multiple	0	0
8160311	Penetrating injury toe, single or multiple - superficial; minor	0	0
9100001	Soft tissue (skin) injury NFS	2	0
9102001	Soft tissue (skin) injury - abrasion	932	699

AIS code [1]	Injury description [1] *	Incidence (28 793 study patients)	Incidence (20 813 analysis patients)
9104001	Soft tissue (skin) injury - contusion; hematoma	302	207
9106001	Soft tissue (skin) injury - laceration	159	105
9108001	Soft tissue (skin) injury - avulsion	0	0
9140001	Degloving injury - General	7	5
9160001	Penetrating injury - General	9	7

* NFS - Not Further Specified.

1. Adapted from Gennarelli TA, Wodzin E, eds. Abbreviated Injury Scale 2005 - Update 2008. Barrington, IL: AAAM; 2008.

Comparison of revised Functional Capacity Index scores with Abbreviated Injury Scale 2008 scores in predicting 12-month severe trauma outcomes

CS Palmer, PA Cameron, BJ Gabbe

Supplement 2
Development of the Functional Capacity Additive Score and Functional Capacity Quadratic Score

Contents

Introduction

Injury severities assigned by the 2008 predictive Functional Capacity Index (FCI)[1] are only weakly associated with functional outcome.[2] However, the majority of severely injured patients sustain multiple injuries.[2] This suggests that summary scores may be of benefit in improving the predictive value of the FCI.[3] Methods have been developed for generating overall FCI scores for the larger FCI instrument on which the predictive FCI is based,[3] However, no method has yet been developed for the FCI as included in the 2008 Abbreviated Injury Scale (AIS).[1]

The likelihood of poorer outcome increases only incrementally with increasing FCI severity.[2] As such, an additive method of combining FCI scores may be more accurate than a multiplicative method. The two most commonly-used methods for generating patient summary scores using AIS data are the Injury Severity Score (ISS)[4] and the New Injury Severity Score (NISS).[5] Both use a quadratic method, where the worst three injury severities (either within different regions, or overall) are squared and summed. A similar process was used to generate a second score. As with both the ISS and NISS, up to three worst injuries were included in each score.

This supplement details the construction of additive and quadratic summary scores for use with FCI data, and provides examples of their calculation. FCI scores are derived from AIS codes which are used to code each patient's injury or injuries.

Functional Capacity Additive Score (FCAS)

The scale used by the FCI runs counter to that used by the AIS, with scores of 5 predicted to have the best recovery and scores of 1 the worst.[6,7] The initial intent of the FCAS was to simply add these scores. However, this would penalise patients with fewer than three injuries, as they would have lower scores than patients with three or more injuries. As a result, one point was subtracted from each score (ie, running from 4 to 0 rather than 5 to 1), and a score of 5 was used as a mathematical place-holder for each instance where fewer than three injuries were coded.

To construct the FCAS, the three worst FCI severities each had one point deducted from their severity before the three numbers were added. Where fewer than three injuries had received AIS codes, 5 points were added for each injury fewer than three, i.e., where only two injuries were coded 5 points was added, and 10 points if only one injury had been coded. Body region of injury was ignored for calculation.

The FCAS consequently ranges from 0 (poorest predicted outcome; three injuries of FCI level 1) to 14 (best predicted outcome; a single injury of FCI level 5). Suggested grouping of the FCAS is:

Mild injury	*12 - 14*	*Highest likelihood of good recovery*
Moderate injury	*10 - 11*	
Serious injury	*8 - 9*	
Severe injury	*5 - 7*	
Critical injury	*0 - 4*	*Lowest likelihood of good recovery*

Functional Capacity Quadratic Score (FCQS)

AIS codes run from 1 (minor) to 6 (maximal).[1] It is mathematically simpler to construct multiplicative summary measures where higher numbers correspond to higher severity. Consequently, FCI scores were reversed for generating the FCQS - so an injury of FCI 5 severity became 1; of FCI 4 severity, 2 and so on.

To construct the FCQS, the three worst FCI severities were reversed, squared and summed. Where fewer than three injuries were coded, only the squared severities from the injury or injuries coded were used. Body region of injury was ignored for calculation.

The FCQS consequently ranges from 1 (best predicted outcome; a single injury of FCI level 5) to 75 (poorest predicted outcome; three injuries of FCI level 1). In practice, this was equivalent to a NISS value,[5] but derived using FCI severities instead of AIS severities. Suggested grouping of the FCQS is:

Mild injury	*1 - 11*	*Highest likelihood of good recovery*
Moderate injury	*9 - 15*	
Serious injury	*16 - 24*	
Severe injury	*25 - 39*	
Critical injury	*40 - 75*	*Lowest likelihood of good recovery*

Sample calculation of FCAS and FCQS for three patients

Overleaf, eTable 3 lists the injuries sustained by five sample patients, illustrating differences in overall severity estimates using different scores. Summary NISS is shown for each patient for comparison. One patient uses example injuries taken from introductory sections of AIS dictionaries (codes changed to reflect 2008 AIS severities).[1,8]

Patient 1 describes a multitrauma patient, as might be seen in (for example) a high fall. According to NISS there is a high mortality likelihood (critical injuries), but (assuming survival) only a mild risk to functional recovery according to FCAS and FCQS.

Patient 2 describes a patient with an essentially isolated head injury with an accompanying superficial injury, as might be seen in (for example) a low fall. The NISS is moderate, and the FCAS and FCQS give moderate to severe scores.

Patient 3 describes a patient with an injury to the lower torso, as might be seen in (for example) a motor vehicle collision with a lap seat belt worn. The NISS and FCAS are severe, and the FCQS is critical.

Patient 4 describes a patient with injuries to the face and lower leg, as might be seen in (for example) a motorbike fall. The NISS describes only mild injury, but the FCAS and FCQS are both severe.

Patient 5 describes a patient with an isolated injury to the cervical spine, as might be seen in (for example) a diving injury. The NISS is serious; the FCAS, moderate and the FCQS severe.

References

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eTable 3. Sample patients illustrating score adjustments and calculation of FCAS and FCQS.

Injury description	AIS code [1]	FCI [1] severity	One of three worst injuries?		NISS [5] calculation	FCAS calculation	FCQS calculation	
			AIS	FCI		Adjusted FCI severity for FCAS calculation	Adjusted FCI severity for FCQS calculation	FCQS severity [2]
Patient 1 [1,8]								
Cerebral contusion	140602.3	5	Not used [*]	Yes	9	4	1	1
Small right temporal epidural hematoma	140632.4	5	Yes	Yes	16	4	1	1
Internal carotid artery, complete transection	320212.4	5	Yes	Yes	16	4	1	1
Ear laceration	210600.1	5	No	Not used				
Rib fractures, left side, ribs 3-4	450202.2	5	No	Not used				
2cm laceration right lobe of liver, posterior	541822.2	5	No	Not used				
Retroperitoneal hematoma	543800.2	5	No	Not used				
Fracture C4 right lamina and facet	650217.2	5	No	Not used				
Gunshot wound left small toe	816030.1	5	No	Not used				
Fractured femur	853000.3	5	Yes	Not used				
Overall abrasions	910200.1	5	No	Not used				
					NISS = 41	***FCAS = 12***		***FCQS = 3***
Patient 2								
Right parietal superficial scalp laceration	110602.1	5	Yes	Yes	1	4	1	1
Thrombosis right posterior cerebral artery	121804.3	2	Yes	Yes	9	1	4	16
				Placeholder	*0*	*5*	*0*	*0*
					NISS = 10	***FCAS = 10***		***FCQS = 17***

Injury description	AIS code [1]	FCI [1] severity	One of three worst injuries?		NISS [5] calculation	FCAS calculation	FCQS calculation	
			AIS	FCI		Adjusted FCI severity for FCAS calculation	Adjusted FCI severity for FCQS calculation	FCQS severity [2]
Patient 3								
Seatbelt bruising across abdomen	510402.1	5	Yes	Yes	1	4	1	1
Laceration to bladder, involving bladder neck	540626.4	2	Yes	Yes	16	1	4	16
Complete cauda equina syndrome; fracture L2	630634.4	1	Yes	Yes	16	0	5	25
					NISS = 33	***FCAS = 5***		***FCQS = 42***
Patient 4								
Closed fracture mandibular symphysis	250606.1	5	Yes	Yes	1	4	1	1
Complete articular fracture distal tibia	854371.2	2	Yes	Yes	4	1	4	16
Calcaneus fracture	857300.2	3	Yes	Yes	4	2	3	9
Bruising to face, chest and both legs	910400.1	5	Not used	Not used				
					NISS = 9	***FCAS = 7***		***FCQS = 26***
Patient 5								
C1/2 dislocation with incomplete cord syndrome	640216.4	1	Yes	Yes	16	0	5	25
				Placeholder	*0*	*5*	*0*	*0*
				Placeholder	*0*	*5*	*0*	*0*
					NISS = 16	***FCAS = 10***		***FCQS = 25***

* Not used - injury was of equal AIS/FCI severity to injury codes used in calculation, but limit of three injury codes per patient had been reached.

Comparison of revised Functional Capacity Index scores with Abbreviated Injury Scale 2008 scores in predicting 12-month severe trauma outcomes

CS Palmer, PA Cameron, BJ Gabbe

Supplement 3
Sensitivity analysis for data using age restrictions

Contents

Introduction

Overleaf, eTable 4 provides a summary of the results of adding different methods of classifying injury severity to models predicting 12-month functional outcomes after serious injury, when the models were restricted to using patients from particular age groups only. The training dataset of 13,885 adult trauma patients who were followed-up at 12 months was used. One column duplicates the data presented in a comparable column of Table 2 in the main manuscript, for ease of comparison of results.

Restricting the age of patients evaluated (to patients aged 18-34 years only, or 18-54 years only) within the training dataset did not consistently result in improved model discrimination (eTable 4). For most outcome measures, models derived using all patients had higher areas under the ROC curve (AUC) than those using restricted age groups. Restricting the age groups used in models only produced consistently higher AUC for the outcomes of return to work, and the EQ-5D pain/discomfort and anxiety/depression items. Even so, none of the models for the latter two outcomes exceeded an AUC of 0.60. Discrimination and calibration were generally acceptable, although across all models used in both age-restricted groups there were more models with unacceptable calibration levels than when the whole dataset was used.

eTable 4. Discrimination and calibration of models in the training dataset (total n = 13 885 patients) for successive age restrictions.

Model outcome	All patients (total n=13 885) [a]	Patients aged 18-54 years (total n=7958)		Patients aged 18-34 years (total n=3933)	
	Area under ROC curve (99% CI)	**Area under ROC curve (99% CI)**	**Ungrouped Pearson X^2 statistic (p-value)**	**Area under ROC curve (99% CI)**	**Ungrouped Pearson X^2 statistic (p-value)**
GOS-E [b] outcome	**(n=13 866)**	**(n=7945)**		**(n=3926)**	
Age and gender	0.762 (0.748 to 0.777)	0.556 (0.527 to 0.583)	7942.9 (0.986)	0.555 (0.512 to 0.599)	3928.3 (0.974)
Age, gender and no. of injuries	0.768 (0.755 to 0.783)	0.631 (0.603 to 0.659)	7901.7 (0.772)	0.655 (0.613 to 0.697)	3911.1 (0.881)
Age, gender and MAIS [c]	0.779 (0.766 to 0.793)	0.665 (0.637 to 0.693)	8084.2 (0.482)	0.689 (0.649 to 0.729)	3969.3 (0.763)
Age, gender and ISS [d]	0.781 (0.768 to 0.794)	0.673 (0.645 to 0.700)	7909.4 (0.846)	0.704 (0.665 to 0.744)	3823.6 (0.405)
Age, gender and NISS [e]	0.779 (0.766 to 0.793)	0.674 (0.646 to 0.701)	7894.5 (0.783)	0.701 (0.662 to 0.739)	3815.4 (0.358)
Age, gender and worst FCI [f]	0.779 (0.766 to 0.792)	0.684 (0.658 to 0.711)	7965.9 (0.734)	0.722 (0.684 to 0.760)	3892.8 (0.578)
Age, gender and FCAS [g]	0.778 (0.765 to 0.791)	0.679 (0.653 to 0.706)	7835.1 (0.056)	0.714 (0.677 to 0.751)	3574.8 (0.003)
Age, gender and FCQS [h]	0.785 (0.772 to 0.798)	0.691 (0.664 to 0.717)	7754.9 (0.265)	0.727 (0.689 to 0.765)	3714.1 (0.060)
Return to work outcome	**(n=8132)**	**(n=6565)**		**(n=3389)**	
Age and gender	0.527 (0.509 to 0.545)	0.514 (0.494 to 0.534)	6564.9 (0.996)	0.525 (0.497 to 0.554)	3388.9 (0.996)
Age, gender and no. of injuries	0.632 (0.614 to 0.650)	0.637 (0.617 to 0.657)	6656.7 (0.859)	0.638 (0.609 to 0.666)	3387.3 (0.951)
Age, gender and MAIS [c]	0.601 (0.583 to 0.618)	0.602 (0.582 to 0.622)	6557.7 (0.882)	0.607 (0.579 to 0.634)	3382.7 (0.844)
Age, gender and ISS [d]	0.627 (0.610 to 0.645)	0.630 (0.610 to 0.650)	6579.8 (0.772)	0.635 (0.607 to 0.663)	3396.3 (0.815)
Age, gender and NISS [e]	0.622 (0.604 to 0.639)	0.626 (0.606 to 0.646)	6547.8 (0.720)	0.627 (0.600 to 0.654)	3376.2 (0.651)
Age, gender and worst FCI [f]	0.637 (0.619 to 0.655)	0.634 (0.614 to 0.654)	6550.0 (0.008)	0.628 (0.600 to 0.655)	3382.8 (0.290)
Age, gender and FCAS [g]	0.650 (0.632 to 0.667)	0.652 (0.633 to 0.672)	6545.9 (0.376)	0.645 (0.617 to 0.672)	3375.4 (0.078)
Age, gender and FCQS [h]	0.643 (0.625 to 0.661)	0.644 (0.624 to 0.664)	6537.6 (0.527)	0.638 (0.610 to 0.665)	3375.5 (0.586)
EQ-5D mobility outcome	**(n=12 200)**	**(n=6852)**		**(n=3363)**	
Age and gender	0.683 (0.670 to 0.696)	0.556 (0.537 to 0.575)	6851.5 (0.990)	0.534 (0.505 to 0.563)	3363.1 (0.995)
Age, gender and no. of injuries	0.702 (0.689 to 0.714)	0.622 (0.602 to 0.641)	6851.0 (0.986)	0.622 (0.593 to 0.650)	3361.6 (0.961)
Age, gender and MAIS [c]	0.688 (0.675 to 0.700)	0.571 (0.552 to 0.591)	6851.9 (0.998)	0.554 (0.526 to 0.583)	3363.5 (0.982)
Age, gender and ISS [d]	0.694 (0.681 to 0.706)	0.590 (0.570 to 0.609)	6862.1 (0.835)	0.581 (0.552 to 0.610)	3370.0 (0.785)

Model outcome	All patients (total n=13 885) [a]	Patients aged 18-54 years (total n=7958)		Patients aged 18-34 years (total n=3933)	
	Area under ROC curve (99% CI)	Area under ROC curve (99% CI)	Ungrouped Pearson X^2 statistic (p-value)	Area under ROC curve (99% CI)	Ungrouped Pearson X^2 statistic (p-value)
Age, gender and NISS [e]	0.690 (0.678 to 0.703)	0.586 (0.566 to 0.605)	6846.7 (0.908)	0.581 (0.553 to 0.609)	3358.9 (0.865)
Age, gender and worst FCI [f]	0.720 (0.708 to 0.732)	0.676 (0.658 to 0.693)	6774.3 (<0.0001)	0.680 (0.654 to 0.706)	3308.5 (<0.0001)
Age, gender and FCAS [g]	0.725 (0.713 to 0.737)	0.692 (0.674 to 0.709)	6800.8 (0.010)	0.704 (0.678 to 0.730)	3303.3 (<0.0001)
Age, gender and FCQS [h]	0.720 (0.708 to 0.732)	0.679 (0.661 to 0.697)	6798.2 (0.342)	0.687 (0.661 to 0.714)	3313.1 (0.072)
EQ-5D personal care outcome	**(n=12 196)**	**(n=6850)**		**(n=3359)**	
Age and gender	0.710 (0.696 to 0.725)	0.589 (0.566 to 0.613)	6833.1 (0.857)	0.571 (0.532 to 0.610)	3357.1 (0.973)
Age, gender and no. of injuries	0.722 (0.709 to 0.736)	0.640 (0.616 to 0.664)	6824.0 (0.816)	0.632 (0.593 to 0.671)	3357.2 (0.979)
Age, gender and MAIS [c]	0.717 (0.703 to 0.731)	0.620 (0.596 to 0.643)	6822.5 (0.786)	0.626 (0.588 to 0.664)	3368.7 (0.902)
Age, gender and ISS [d]	0.721 (0.707 to 0.735)	0.633 (0.610 to 0.656)	6819.2 (0.784)	0.641 (0.603 to 0.680)	3347.7 (0.879)
Age, gender and NISS [e]	0.718 (0.704 to 0.732)	0.627 (0.604 to 0.651)	6807.2 (0.697)	0.636 (0.598 to 0.673)	3335.6 (0.748)
Age, gender and worst FCI [f]	0.723 (0.709 to 0.737)	0.648 (0.624 to 0.671)	6797.0 (0.350)	0.648 (0.610 to 0.685)	3348.2 (0.787)
Age, gender and FCAS [g]	0.725 (0.711 to 0.739)	0.652 (0.629 to 0.675)	6787.8 (0.126)	0.654 (0.618 to 0.691)	3329.0 (0.384)
Age, gender and FCQS [h]	0.727 (0.713 to 0.740)	0.650 (0.626 to 0.673)	6771.5 (0.488)	0.653 (0.616 to 0.690)	3318.8 (0.574)
EQ-5D usual activities outcome	**(n=12 186)**	**(n=6848)**		**(n=3359)**	
Age and gender	0.598 (0.585 to 0.611)	0.565 (0.547 to 0.583)	6847.7 (0.989)	0.566 (0.540 to 0.591)	3358.6 (0.979)
Age, gender and no. of injuries	0.632 (0.619 to 0.645)	0.629 (0.612 to 0.647)	6869.8 (0.527)	0.630 (0.605 to 0.655)	3363.3 (0.845)
Age, gender and MAIS [c]	0.601 (0.588 to 0.614)	0.572 (0.554 to 0.589)	6847.5 (0.980)	0.573 (0.548 to 0.599)	3357.8 (0.937)
Age, gender and ISS [d]	0.613 (0.600 to 0.626)	0.591 (0.574 to 0.609)	6844.7 (0.902)	0.597 (0.571 to 0.622)	3358.4 (0.975)
Age, gender and NISS [e]	0.609 (0.596 to 0.622)	0.589 (0.571 to 0.606)	6847.0 (0.969)	0.591 (0.566 to 0.617)	3357.4 (0.928)
Age, gender and worst FCI [f]	0.630 (0.617 to 0.643)	0.623 (0.605 to 0.640)	6852.8 (0.193)	0.621 (0.596 to 0.646)	3356.5 (0.613)
Age, gender and FCAS [g]	0.639 (0.626 to 0.651)	0.638 (0.621 to 0.655)	6859.6 (0.560)	0.639 (0.615 to 0.664)	3357.4 (0.750)
Age, gender and FCQS [h]	0.632 (0.619 to 0.645)	0.627 (0.609 to 0.644)	6867.0 (0.516)	0.625 (0.600 to 0.650)	3359.7 (0.971)
EQ-5D pain/discomfort outcome	**(n=12 109)**	**(n=6815)**		**(n=3339)**	
Age and gender	0.530 (0.517 to 0.544)	0.562 (0.544 to 0.580)	6815.7 (0.959)	0.572 (0.546 to 0.597)	3338.8 (0.989)
Age, gender and no. of injuries	0.584 (0.571 to 0.597)	0.609 (0.592 to 0.627)	6824.6 (0.712)	0.612 (0.587 to 0.636)	3343.3 (0.814)

Model outcome	All patients (total n=13 885) [a]	Patients aged 18-54 years (total n=7958)		Patients aged 18-34 years (total n=3933)	
	Area under ROC curve (99% CI)	Area under ROC curve (99% CI)	Ungrouped Pearson X^2 statistic (p-value)	Area under ROC curve (99% CI)	Ungrouped Pearson X^2 statistic (p-value)
Age, gender and MAIS [c]	0.540 (0.527 to 0.554)	0.562 (0.544 to 0.580)	6815.5 (0.937)	0.572 (0.547 to 0.598)	3338.4 (0.987)
Age, gender and ISS [d]	0.538 (0.525 to 0.551)	0.568 (0.550 to 0.586)	6815.1 (0.996)	0.578 (0.553 to 0.604)	3338.5 (0.971)
Age, gender and NISS [e]	0.534 (0.521 to 0.548)	0.564 (0.547 to 0.582)	6816.0 (0.946)	0.574 (0.549 to 0.599)	3338.7 (0.979)
Age, gender and worst FCI [f]	0.549 (0.535 to 0.562)	0.581 (0.564 to 0.599)	6816.6 (0.364)	0.586 (0.561 to 0.612)	3338.1 (0.902)
Age, gender and FCAS [g]	0.570 (0.557 to 0.584)	0.598 (0.580 to 0.616)	6824.8 (0.245)	0.603 (0.578 to 0.628)	3340.4 (0.599)
Age, gender and FCQS [h]	0.554 (0.541 to 0.568)	0.582 (0.564 to 0.599)	6820.3 (0.761)	0.587 (0.561 to 0.612)	3339.3 (0.982)
EQ-5D anxiety/depression outcome	**(n=12 082)**	**(n=6797)**		**(n=3335)**	
Age and gender	0.544 (0.530 to 0.558)	0.543 (0.525 to 0.562)	6796.2 (0.964)	0.577 (0.551 to 0.603)	3334.0 (0.962)
Age, gender and no. of injuries	0.574 (0.560 to 0.587)	0.587 (0.569 to 0.605)	6794.5 (0.922)	0.608 (0.582 to 0.633)	3331.0 (0.865)
Age, gender and MAIS [c]	0.552 (0.541 to 0.569)	0.562 (0.543 to 0.580)	6796.8 (0.993)	0.592 (0.566 to 0.618)	3336.4 (0.952)
Age, gender and ISS [d]	0.568 (0.554 to 0.582)	0.580 (0.562 to 0.598)	6796.5 (0.984)	0.606 (0.580 to 0.632)	3336.3 (0.959)
Age, gender and NISS [e]	0.566 (0.552 to 0.579)	0.579 (0.560 to 0.597)	6795.8 (0.962)	0.605 (0.579 to 0.631)	3335.0 (0.999)
Age, gender and worst FCI [f]	0.557 (0.543 to 0.570)	0.566 (0.548 to 0.584)	6795.6 (0.826)	0.594 (0.568 to 0.620)	3334.9 (0.993)
Age, gender and FCAS [g]	0.567 (0.553 to 0.581)	0.578 (0.559 to 0.596)	6794.2 (0.198)	0.603 (0.577 to 0.629)	3332.1 (0.751)
Age, gender and FCQS [h]	0.561 (0.547 to 0.574)	0.570 (0.551 to 0.588)	6795.7 (0.953)	0.598 (0.572 to 0.624)	3333.9 (0.961)

[a] As per Table 2 in the main manuscript; for comparison purposes only.

[b] GOS-E - Extended Glasgow Outcome Scale.

[c] MAIS - Maximum 2008 Abbreviated Injury Scale severity.

[d] ISS - Injury Severity Score.

[e] NISS - New Injury Severity Score.

[f] Worst FCI - Worst 2008 predictive Functional Capacity Index score.

[g] FCAS - Functional Capacity Additive Score (based on three worst FCI scores).

[h] FCQS - Functional Capacity Quadratic Score (based on up to three worst FCI scores).