WAR SURGICAL EXPERIENCE REDUCES OPERATION TIMES AND SAVES LIVES: A COMPREHENSIVE ANALYSIS OF ALL TRAUMA SUSTAINED IN THE AFGHANISTAN CONFLICT 2009-2014 PRIORITISES THE SURGICAL PROCEDURES TO IMPROVE TRAINING AND READINESS FOR FUTURE ARMED CONFLICTS, TERROR ATTACKS, AND CIVILIAN DAMAGE CONTROL SURGERY

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War surgical experience reduces operation times and saves lives: A comprehensive analysis of all trauma sustained in the Afghanistan Conflict 2009-2014 prioritises the surgical procedures to improve training and readiness for future armed conflicts, terror attacks, and civilian damage control surgery

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This thesis is submitted in partial fulfilment for the degree of

Doctor of Medicine (MD)

at the University of St Andrews

May 2018

George, Mum and De

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I, Laura Mary Rose Maitland, do hereby certify that this thesis, submitted for the degree of MD, which is approximately 52,000 words in length, has been written by me, and that it is the record of work carried out by me, or principally by myself in collaboration with others as acknowledged, and that it has not been submitted in any previous application for any degree.

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Abstract

Background: Between 2009 and the end of UK combat operations in Helmand, Afghanistan (2014), each consecutive surgical procedure carried out by the multinational, military surgical team at the Medical Treatment Facility, Camp Bastion was collated. Through analysis I aim to develop the template for prioritising surgical procedures to improve surgical training and readiness for future armed conflicts and terror attacks.

Methods: All surgical teams operating in Camp Bastion filled out detailed, handwritten theatre logbooks for each surgical case. I transcribed all 10,891 consecutive surgical cases, and 20,266 surgical procedures, into an electronic format. I provide for the first time the distinct, original and stand-alone surgical database for this thesis: the "Maitland Module", the largest of its kind.

Results: I present a new analysis and classification of surgery by anatomical region which accounts for the impact of the multiplicity of wounding caused by explosion on surgical workload. I present the first evidenced-based skill set requirement for war, including the most frequently performed humanitarian surgical procedures and their impact on the skill set required of a surgeon in armed conflict. I show that surgical experience predicted shorter operation times for blast trauma. I found that surgical experience of >50 blast trauma cases predicted lower fatality rates. Skill atrophy in surgical competence between conflicts exists, with an associated rise in preventable loss of life at the start of conflict.

Discussion:

I propose that the Complex Attack Surgical Team (CAST) of surgeons, with >50 blast trauma case experience, be on standby in the event of a terrorist attack in the UK to support the currently blast-naive civilian surgeons.

I hope that the template for surgical procedures may lead to standardisation and prioritisation of the skill set requirement for: trauma surgical training; NATO curriculum development; and intelligent, risk-assessed, deployment of surgeons to conflict zones.

Subject related publications arising from the study:

See Chapter 1 and Appendix 1: Maitland, L, Lawton, G, Baden, J, Cubison, T, Rickard, R, Kay, A, and Hettiaratchy, S. (2016) The Role of Military Plastic Surgeons in the Management of Modern Combat Trauma: An Analysis of 645 Cases. Plast Reconstr Surg. 137(4), pp.717-724.

See Appendix 2: The role of plastic surgeons in frontline combat operations: a three-year evaluation, at the Winter Scientific Meeting, 27-29 November 2013, meeting hosted by the British Association of Plastic and Reconstructive and Aesthetic Surgeons (BAPRAS), The Convention Centre, Dublin, Ireland.

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Thesis Outline

Between 2009 and the end of UK combat operations in Afghanistan, a comprehensive and complete inventory of the surgical procedures carried out by the multinational military surgical team at the Role 3 Medical Treatment Facility, Camp Bastion, Helmand Province was collated and analysed. The aim of this thesis is to develop a template for surgical procedures to improve readiness for future armed conflicts and terror attacks.

Chapter 1 aims to validate the concept and benefit of a record of surgical procedures carried out in Afghanistan, and the thesis data set, and presents a preliminary paper published in 2016 in the Journal of Plastic, Reconstructive and Aesthetic Surgery (JPRAS) (Maitland et al., 2016).

Chapter 2, the introduction, provides a literature review and outlines the areas this study will focus upon, chapter by chapter. Each chapter is written as a discrete study in readiness for publication. An evidence-based standardisation for the surgical procedures required for war, that is internationally agreed upon does not currently exist. I discuss that by identifying the surgical procedures most frequently used in our most recent armed conflict we can improve preparation, training and preparedness to manage the poly-trauma injuries associated with explosions and blast trauma.

In Chapter 3 we provide a description of the database and methods used in the thesis. I describe the methodology for the thesis, including how the database was designed.

All surgical teams operating in Camp Bastion filled out detailed, handwritten, on the spot, theatre logbooks for each surgical case. In order to interrogate this comprehensive hand-written record, I transcribed a total of 10,891 consecutive surgical cases into an electronic format. Some data was re-coded during entry and summarised into additional fields for additional analysis (see Chapter 3 Methods). I provide for the first time the distinct, original, and stand-alone surgical database for this thesis: the "Maitland Module". The dataset represents the largest complete set of surgical interventions carried out from any armed conflict to date.

Further methodology is described in subsequent chapters (4-7) as distinct to one another, but using the same database throughout.

Chapter 4 provides the first analysis of the largest consecutive surgical database to come from any conflict. I compare the findings to past classifications of surgical procedures from similar, but partial and much smaller, studies of previous years of the conflict in Afghanistan to highlight key differences, and to situate the database within the literature. I used a similar methodology to enable comparison of findings between previous studies and to highlight key differences to previous classifications of surgical workload in war. Chapter 4 shows that the comprehensive skill set of surgical procedures for conflict is yet to be determined. I discuss whether the surgical skill sets proposed so far need to be adapted because of our findings.

Chapter 5 describes the surgical burden of Disease and Non-Battle Injuries in conflict zones. It describes the humanitarian surgery performed on the civilian population (adults, children and interpreters) caught up in war. I determine the origin of casualties by case nationality, and use this as a proxy to examine any differences in surgical procedures for the civilian population that was not wearing protective body armour - and who subsequently returned to relatively poor local healthcare facilities in Afghanistan - compared to those in the population who were wearing body armour (International Security Assistance Forces). I investigate demographic variability in case fatality rates between these populations in order to assess the possible impact of nationality on definitive surgical care provision. The aim of Chapter 5, therefore, is to enable the development of the surgical template for DNBI and humanitarian surgery. I anticipate that in future armed conflicts surgical provision for civilian casualties will remain an important factor in accordance with the Geneva Conventions, and with it the surgical management for DNBI. I anticipate that this study will have implications for future surgical planning for armed conflicts and terror attacks.

In Chapter 6 I further explore the surgical impact of blast injuries, and the multiplicity of wounding that was typified by the conflict in Afghanistan. To account for the polytrauma nature of wounding sustained by blast/explosions, a new approach to analysis of surgical procedures was developed. Here, the methodology differed from previous studies, where surgical procedures were recorded as occurring once per case (i.e. patient) despite being performed, in some instances on multiple regions per case (as described in Chapter 4). Battle-Injury (BI) surgical procedures are examined and I develop a new categorisation of both primary and secondary (take-back) BI cases by anatomical region. In this way I aim to account for the polytrauma nature of casualties and to present a complete analysis of all surgical procedures from Afghanistan 2009-2014. I present the surgical procedures used most commonly, and establish the most commonly operated upon body regions. Following this, I allocate the procedures to appropriate surgical specialisms and compare this to previous analyses in this area.

The findings of Chapter 6 show the surgery most frequently used to save life, eyesight and limb in the Afghanistan armed conflict. Future armed conflict might change, but required surgical skills might not. I recognise that one surgeon cannot do it all, but we hope that the findings of Chapter 6 enable a discussion of a more generalist approach to surgical training for future conflict.

Chapter 7 aims to consolidate the work outlined in the previous chapters, and to present a new evidence-based surgical template for the core surgical procedures by anatomical region. With the conflict in Afghanistan fading, I investigate further the concern that there is a “slipping back” in surgical competence and experience between conflicts, or skill fade. I examine what impact this may, or may not, have on surgical outcome. I modified the methodology described in Chapter 6 to analyse the most severe cases: i.e. those of primary damage control surgery of the most severely injured casualties, and to address the impact this may have upon outcome measures, using primarily case fatality, or length of surgical procedure. As blast injuries increasingly occur in peacetime, the surgical template proposed in Chapter 7 is no-longer confined to the military or armed conflicts. With the increase in terror attacks in cities at home, I hope the surgical template may improve readiness for blast injuries seen both in terror attacks and armed conflicts.

In Chapter 8 I summarise our research findings, discuss limitations and challenges, and conclude by defining the scope for future research.

Chapter 1

Introduction

The following paper, Journal of Plastic, Reconstructive and Aesthetic Surgery (JPRAS) (Maitland et al., 2016) describes data gathered from surgeons' personal logbooks over four periods (2009-2012).

Maitland et al., (2016) examined the cases which involved plastic surgeons to establish their role in modern conflict. The following paper describes an initial look at the data set and examines the role of plastic surgeons, in the Afghanistan conflict.

The purpose of this initial examination was to validate (within the context of Army protocol and ethics) the concept and benefit of the record of surgical procedures carried out in Afghanistan and the present study's dataset.

After publication additional analysis was carried out, see results section in italics and * to denote amended figures.

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Full Title: The role of military plastic surgeons in the management of modern combat trauma: an analysis of 645 cases

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The above authors declare that there are no conflicts of interest with this research and no external sources of funding were received, nor has this research been inappropriately biased by affiliation with commercial, or otherwise, organisations.

ABSTRACT:

Introduction

Plastic surgery has historically been linked to war. Between 2008 and the end of combat operations in Afghanistan (2014), British military plastic surgeons formed part of the multinational military surgical team at the Role 3 Medical Treatment Facility, Camp Bastion, Helmand Province. The present study aimed to analyse the activity of these surgeons objectively and to determine the utility of their deployment.

Methods

Data was gathered prospectively from five periods (2009-2012). This coincided with different surgeons, different types of combat activity, different wounding patterns and different mission emphases for the hospital. Various metrics were measured.

Results

Plastic surgeons were involved in 40% of surgical cases (645/1654). This was consistent, despite changes in the predominant wounding mechanism and casualty population. One third of cases involved the plastic surgeon as the lead or sole surgeon and two thirds involved working with surgeons from other disciplines. Caseload by anatomical region was: hand and upper limb 64%; head and neck 46%; lower limb 40%; trunk 25%. A median of 1.75 body areas were operated on per patient. Involvement did not differ between patients wearing combat-body-armour when injured and those who were not.

Discussion

Plastic surgeons played a significant role in the management of modern military trauma. This reflects the types of injuries sustained and the expertise of military plastic surgeons complimenting the skill-set of the other surgical team members. The level of activity was independent of wounding patterns, suggesting that the speciality may be a useful, irrespective of the nature of the conflict.

Manuscript Classifications:

Burns; Lower extremity acute trauma; War medicine

INTRODUCTION

UK, US and coalition forces deployed to Southern Afghanistan at various time points after 2006. Injury patterns changed over the course of this conflict, with the increased use of Improvised Explosive Devices (IED) (Belmont et al., 2010). Changes to personal protective equipment (PPE) and improvements in field care and medical evacuation have led to an increase in the numbers of casualties surviving but also to an increase in extremity injuries and amputations (Champion et al., 2010; Ramasamy et al., 2010; Woodward and Eggertson, 2010; Brown and Clasper, 2013). In response to these events, from 2008 the makeup of the multinational surgical teams deployed to the Medical Treatment Facility at Camp Bastion, Southern Helmand Province was adapted to include British plastic surgeons, complementing the traditional team of an orthopedic and a general surgeon (vascular or colorectal surgeon) (Ramasamy et al., 2010). This is in contrast to previous conflicts where plastic surgeons were only involved later in the evacuation chain.

The main drive for the deployment of plastic surgeons to Afghanistan was the increase in the incidence of multiple, complex extremity injuries being sustained. These injuries are challenging to manage and require a multi-disciplinary approach (Nayagam et al., 2011). It is essential that, alongside saving life, a focus is maintained on maximising the outcome for each individual limb, so that the multiple-limb injured patient can achieve the best functional result. This requires the subject matter experts for the different elements of limb salvage, i.e. plastic and orthopedic surgeons, are present from the first surgical intervention. Whilst the paradigm employed on combat operations is that primary amputations are not carried out on coalition forces, this multidisciplinary team can decide whether good long-term function is best achieved by limb salvage and reconstruction or whether amputation and prosthetic rehabilitation would be the better option. Such decisions must be achieved within the time constraints of damage control surgery and multiple casualty scenarios, hence the need to have key decision-makers present from the outset (Brown and Clasper, 2013; Gopal et al., 2000).

This study aims to examine the activity of the plastic surgeon in this scenario. The period studied (2009-2012) coincided with the busiest period of combat for coalition forces, and the highest casualty rates. The domains examined were: how much operative work the deployed plastic surgeons performed and which plastic surgical procedures were most used. Collaboration within the surgical team was also studied. During the period of the study various aspects of combat operations and the consequent casualties changed. The consistency of the involvement of the plastic surgeons despite these changes in injury patterns and type of combat operation was important to ascertain, in order to determine the external validity of experience in this conflict to future combat operations.

METHODS

Patient identification

A comprehensive analysis of prospectively-collected operation logbooks, covering five tours of duty of between six and eight weeks each, was performed to identify all operations carried out by plastic surgeons in the Role 3 Medical Treatment Facility in Camp Bastion. The data covered during four separate time periods between May 2009 and August 2012 (Cohort AD). Operations that did not involve a plastic surgeon were excluded.

Dataset collected

Four domains of data were collected:

i) Plastic surgical activity

This was collected as the percentage of surgical operations performed by the deployed plastic surgeon, against a denominator of all surgical cases. Whether the plastic surgeon operated alone or with other surgeons was determined.

ii) Body regions

The body regions operated on were determined and the total number of body areas treated per patient were analysed.

iii) Nationality of casualties and the use of body armour

The origin of the casualties was determined by nationality. This data was used as a proxy to examine any difference in surgical activity for a population that was wearing protective body armour (coalition forces) and those who did not wear body armour (Afghan forces and local nationals). In addition these data analysed the surgical activity when different types of casualties were being treated, i.e. was the requirement for plastic surgery greater when coalition forces made up most of the casualties or when local nationals were the bulk of the patients treated. This would have implications for future team planning depending on the type of casualties expected for a particular mission.

iv) Type of plastic surgery activity

The types of procedures performed by the plastic surgeons were determined. This would help identify the skill-set required of the team. Procedures were categories into debridement (wound debridements and explorations); salvage (revascularisation and bone stabilisation); reconstruction (skin grafting, use of flaps, nerve repair/reconstruction).

Statistical analysis

Analysis of the data used Pearson Chi-square test, as appropriate, for nominal data. A p-value of < 0.05 was considered statistically significant. Statistical analyses were performed using SPSS version 20.0 software for Windows.

RESULTS

Data from five tours of duty were captured over four separate time periods (cohort A-D). Surgical cases that involved plastic surgeons were selected from between 18th May 2009 and 23rd of August 2012. In total 1654 surgical log book cases were reviewed of which 645 cases were identified as appropriate and analysed (Table 1).

i) Plastic surgical provision

There was a singleton plastic surgeon throughout the operational. They were on call and available 24/7. All deployed surgeons had completed UK residency including subspecialty fellowship training (hand and extremity (2), sarcoma and lower limb (1), head and neck/lower limb (1) and burns (2)). Three of the surgeons had completed residency within six months of first deployment but this involved eight years minimum specialist training and four years of other surgical training. The other three surgeons had been consultants for 2-10 years. Five of the six plastic surgeons underwent the Military Operational Surgical Training (MOST) course pre-deployment training.

ii) Plastic Surgical Activity

Overall plastic surgeons were involved in 40% of all surgical cases. This was consistent throughout the study time period. One third of the plastic surgery cases involved the plastic surgeon operating alone/as the lead (13% of all surgical cases). Two thirds involved working with other surgeons (28% of all surgical cases, Fig.1 and Table 1). Almost half of plastic activity was orthoplastic throughout the study period (Fig.2). A third of the plastic surgery activity was with the complete surgical team (general, plastic, and orthopedic).

**After publication, additional analysis was carried out to ascertain any statistical difference between the levels of plastic surgical activity (Fig.1). There is a significant difference between the level of plastic surgical activity between 2010 and 2011 (Table 1; Fig.1: 43% vs 35%; $z=2.536$; $p<0.05$). There was no significant difference in plastic surgical activity between 2009 and 2010 (43% vs. 43%; $z=1.000$; $p>0.05$) or 2011 and 2012 (35% vs. 37%; $z=-0.625$; $p>0.05$).*

iii) Body regions operated on

64% of cases involved the upper limb (Table 2). Of these, 28% were hand injuries and 36% were more proximal. 40% involved the lower limb. 58% involved the head and neck which included 32% injuries to face/head scalp and 5% neck and retropharynx. 9% involved traumatic injury to the eyes. 25% of plastic surgical cases involved the trunk, of which 12% were injuries to the abdomen, 7% injuries to the chest/back and 5% were injuries to the buttocks and perineum. None of the variations in the percentage of body areas involved over the study period reach statistical significance.

Plastic surgeons on average operated on 1.75 body regions of trauma per case (Table 2). Overall the regions of body plastic surgeons operated on remained consistent throughout 2009-2012 (Table 2).

iv) Nationality of the casualties and use of body armour

International Security Assistance Force (ISAF)/coalition forces accounted for 41% and Afghan National Security Forces (ANSF) 20% of plastic surgery cases (Fig.3). Civilians accounted for the remainder. When nationality was compared between the first and last cohorts from 2009 and 2012 respectively, there was a statistically significant decrease in the number of ISAF casualties and reciprocal rise in ANSF casualties [Fig.3, cohort A: ISAF, n = 77; ANSF, n =

13; cohort D: ISAF, n = 23; ANSF, n = 79, p = 0.000 (<0.05)]. Civilian casualties accounted for a third of cases that involved plastic surgeons (Fig.3; Civilian including: Local national, contractor, interpreter; n = 136 and paediatric local national casualties, n = 78; n=214/645, 33%). The plastic surgical activity remained constant despite variations in casualty nationality and the consequent change between a population wearing protective body armour (coalition and ANSF) and a non-protected group (civilians) (Fig.3).

v) Type of plastic surgery activity

Plastic surgery procedures were categorised into debridement, salvage or reconstruction. The proportion of reconstruction procedures increased from 6% (2009) to 13% (2012), though this did not reach statistical significance (Fig. 4 and Fig. 5). The debridement activity remained relatively constant at around 72% (range 63-77%). Salvage procedures stayed around 10% (range 9-11%, Fig. 5).

DISCUSSION

The modern specialty of plastic surgery was largely born out of developments in the treatment of injuries sustained during World War 1. This study shows that the need for plastic surgeons on a modern battlefield is great with 40% of all surgical cases in the Afghanistan field hospital involving the plastic surgeon. The majority of these cases were extremity injuries and this is a reflection of the wounding patterns being sustained during this conflict.

The signature wounding mechanism of the conflict in Afghanistan was the IED blast. This led to bilateral lower limb amputations, upper limb fragmentation injuries or amputations and fragmentation to the face and neck (Staruch et al., 2014). In previous conflicts, this severity of injury was not as survivable. In this recent conflict, advances in pre-hospital and acute care mean that these individuals are surviving with one to four severely injured or traumatically amputated limbs. For these servicemen and women, survival is not enough; they need to return to high levels of function in order to achieve a meaningful quality of life. In this scenario it is essential that the maximum functional outcome is achieved for each injured limb.

The first decision in the management of a severely injured limb is often the most important and is done in the acute setting. This decision must be taken by the full complement of the surgeons required for limb salvage (plastic, orthopedic and vascular) so that all options are considered.

This facilitates more rapid management planning and leads to better outcomes (Naique et al., 2006). The current UK military doctrine is that primary amputations are not done in coalition forces in the deployed setting at the index procedure. Definitive surgery is delayed to facilitate patient involvement in the decision further down the evacuation chain. Amputations were only carried out on non-viable limbs with no reconstructive potential as part of the initial debridement of necrotic tissue.

The type of injuries where a plastic surgeon was involved, though mainly extremity, also involved a high proportion of head and neck cases, as well as a smaller number of other body regions. This demonstrates the breadth of specialist expertise required of a military plastic surgeon. In the mix of general, orthopedic and plastic surgeon in the military team, it is possible that the only surgeon with experience of surgical access to the neck is the plastic surgeon. The team is reliant on the plastic surgeon to manage injuries to these areas, including areas that are outside the normal scope of plastic surgical practice, such as ocular injuries. This is reflected in the finding that plastic surgeons operated on a median of 1.75 body regions per patient. Such practice is reflective of the constraints on the size of the team as it is not possible to have every specialty present in the field hospital. To mitigate this, military plastic surgeons underwent additional training in certain disciplines e.g. ophthalmology, so that they could deliver a level of expertise. As well as bringing expertise in different body areas, the plastic surgeon also brings specialist skills, such as the management of complex wounds (debridement and exploration), salvage (vascular repair and bony stabilisation) and reconstructive skills (skin grafting and the use of flaps, and nerve repair). All of these used in the appropriate setting can improve patient outcomes and shorten the time of these patients in hospital. Microsurgical reconstruction was not used due to operational constraints of time and equipment.

In the deployed setting, the plastic surgeon was twice as likely to be working as part of a multidisciplinary team as to be working alone. Again, this is reflective of the nature of the injuries sustained. These patients had most often sustained multiple injuries to different body regions, so surgeons often operated simultaneously for expediency. The most common combination was a plastic surgeon together with an orthopedic surgeon, as would be expected given the high incidence of extremity trauma.

The plastic surgical activity remained consistent despite the majority of casualties changing from ISAF/coalition troops in 2009 to ANSF/local nationals in 2012. This is important as the two different groups represent a population with access to body armour and a population who did not use it. It had been thought that body armour, as it protects the trunk and head, may have led to disproportionately more extremity injuries. In this scenario, one would have predicted a greater need for extremity surgeons (orthopedic and plastic) rather than trunk surgeons (general). In a population without body armour, this situation may have been reversed as the trunk would be unprotected and vulnerable to injury. The current study suggests that this may not be the case as both the need for plastic surgeons and the percentage of extremity operations was the same for both the body amoured and non-body armoured groups. It is not immediately clear why this was but it may have been due to survivor bias in the non-body armoured group, i.e. those with significant trunk/torso injuries did not survive to the field hospital. This has implications for the role of plastic surgeons in future deployed military teams, as they appear to have utility irrespective of the type of injury pattern.

The majority of work performed by the plastic surgeons was surgical debridement with salvage and reconstructive procedures being performed less frequently. This is to be expected, as the treatment pathway for coalition forces involves multiple, staged procedures at deployed and home base locations. Definitive reconstruction is delayed until the appropriate time away from the combat zone. The debridement, particularly of specialist areas such as the face and upper limb, is the critical first step in achieving optimum functional outcomes for casualties. If it is not done adequately then there is risk of developing wound infection and sepsis. This can prove a risk to life and to limb, as many of the infective organisms encountered in combat operations in Afghanistan were multi-drug resistant and difficult to treat pharmacologically. Decisions around extent of debridement carried out was done on a case by case basis by the multi-disciplinary team to mitigate against too aggressive debridement that may lead to the loss of reconstructive options or salvageable tissue and so compromise a casualty's final functional result.

The additional challenge of IED blast wounds is extent of the zone of injury. It is not uncommon for over 50% of body surface area to be affected with multiple limb amputations. Debridement of wounds of this size is a major endeavour for surgical teams and should be carried out quickly and thoroughly by subject matter experts. Meticulous debridement, with a clear understanding of the future reconstructive options, is the foundation of the achieving the best outcomes in this patient group. This is a skill that is fundamental to all military surgeons but the plastic surgeon contributes to this in specialist body areas.

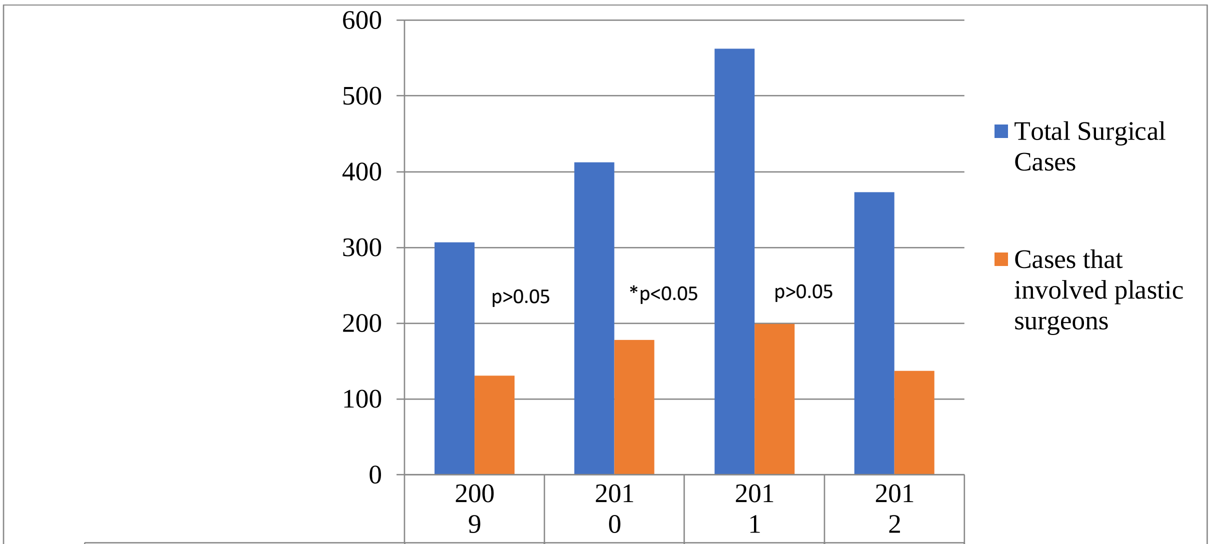
Although the proportion of reconstructive procedures was small, this increased during the study. This was not statistically significant but coincided with a significant increase in the proportion of ANSF casualties. It is likely the two are linked. As stated, coalition casualties are repatriated for future management, including definitive reconstruction. Local nationals did not have this option during this conflict. Reconstructive procedures were performed on this group if they would lead to quicker wound healing (and more rapid discharge) and/or better functional results. All such decisions were made in the context of the activity of the Medical Treatment Facility. Negative pressure wound therapy was introduced in 2011 and this also helped with wound care.

The limitation of this study is that there is no objective evidence of improved functional outcomes from having a plastic surgeon as part of the team. This is difficult to clearly demonstrate for various reasons. The main issue is that there is not a valid control group (i.e. same team but without a plastic surgeon) for comparison. The US surgical team based in Kandahar did not routinely employ a plastic surgeon as part of their establishment. However, differences in their patient pathways and in the patient cohort precluded direct comparison with the current dataset. Data from Camp Bastion that predates 2008 and the deployment of the plastic surgeon would also be non-comparable. The pre-hospital and acute pathways rapidly evolved so that the care being delivered in 2008 differed to that from 2009. However there is evidence from civilian data of the efficacy of having a plastic surgeon involved in severe extremity trauma. Wordsworth et al. looked at a series of 139 open tibial fractures treated sequentially in an urban Major Trauma Centre in the UK. They found that by using an integrated team of orthopedic and plastic surgeons the outcomes were significantly better than those reported in the literature that did not use the approach (1.3% deep infection vs. 38%, 3% non-union vs. 50%) (Wordsworth et al., 2013). A study examining the long-term outcomes of all casualties from recent conflicts is currently under way. This may provide evidence for the benefit of having a plastic surgeon as part of the team. The present cohort study did not allow analysis of the number of delayed amputations that were carried out, however a comprehensive database is available from 2016 and will enable further analysis.

This study shows that if plastic surgeons are deployed as part of a military surgical team, they contribute to a large proportion of the surgical activity. This contribution was irrespective of the injury pattern. The plastic surgeons bring skills and expertise in body areas that will be absent from a team comprised solely of orthopedic and general surgeons. They should be seen as complementary to the team. This study shows that a team consisting of plastic, orthopedic and general surgeons can manage almost all injuries sustained in modern conflict using their normally-practiced and therefore maintained skill sets. Plastic surgery grew out of war; this study suggests that war remains its natural home.

FIGURES and TABLES:

*Figure 1 Proportion of total surgical cases that involved plastic surgeons



	2009	2010	2011	2012
Total Surgical Cases	307	412	562	373
Cases that involved plastic surgeons	131	178	199	137

Fig. 1 Proportion of total cases that involved plastic surgeons per time cohort A-D (2009-2012) (Table 1: total cases involving plastic surgeons, n = 645; total surgical cases n = 1654; 40%).

Figure 2: Who plastic surgeons operated alongside within the multidisciplinary team (2009-2012)

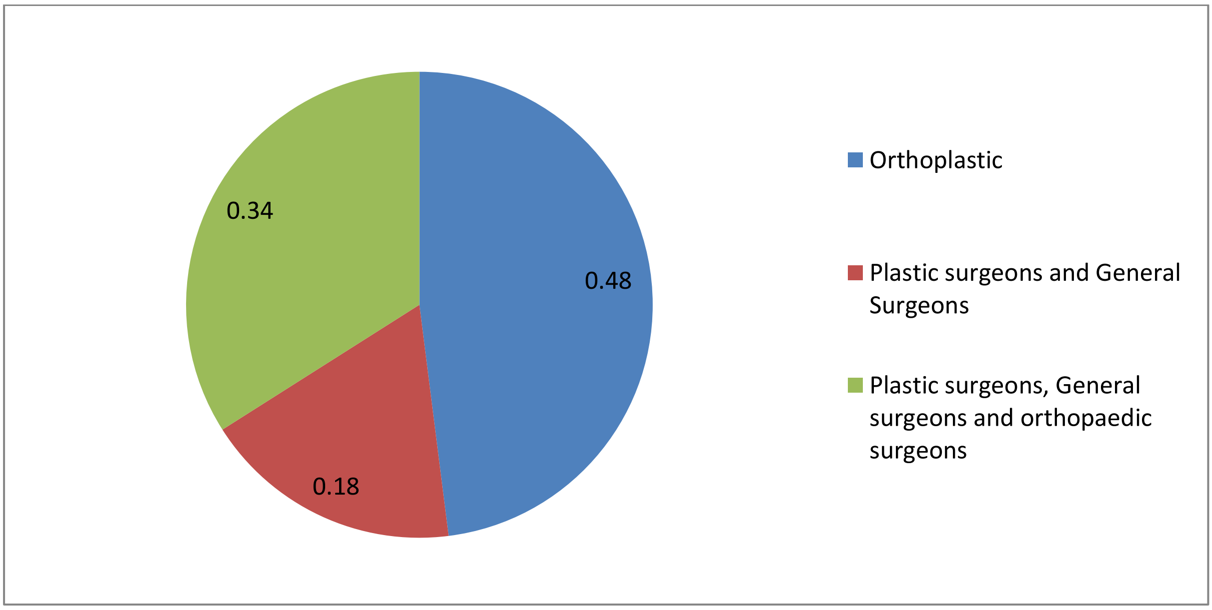


Fig.2 Who plastics operated with (2009-2012) overall as a percentage of all cases involving plastic surgeons (Table 1: n = 463). Percentages are expressed as a proportion of total cases involving plastic surgeons: n = 463; total orthoplastic, n = 223; total plastic and general surgeons, n = 84; plastic general and orthopaedic, n = 156 (Table 2).

*Figure 3: Relationship between casualty nationality and plastic surgical activity (2009-2012)

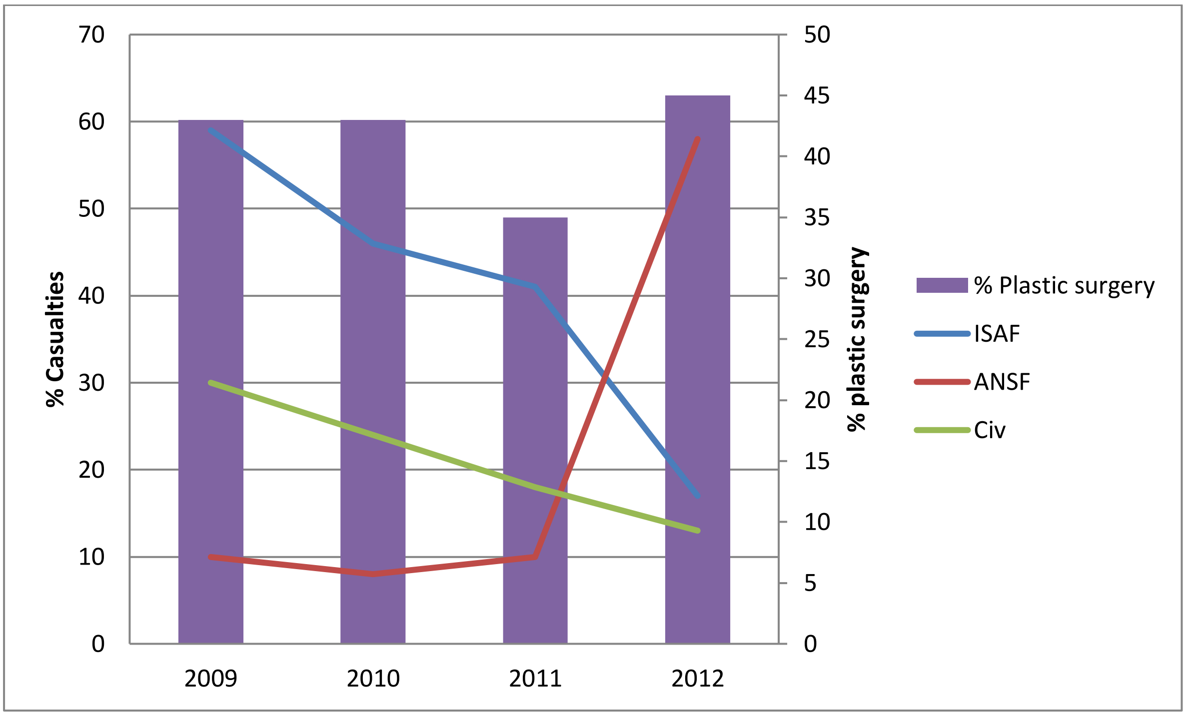


Fig. 3 Percentage of plastic cases of ISAF, ANSF and Civ (civilian) nationality as a percentage of plastic surgical cases (see table 4) versus time (2009-2012) alongside activity of plastic surgeons (percentage of total cases that involved plastics from 2009-2012 (Table 1).

Figure 4

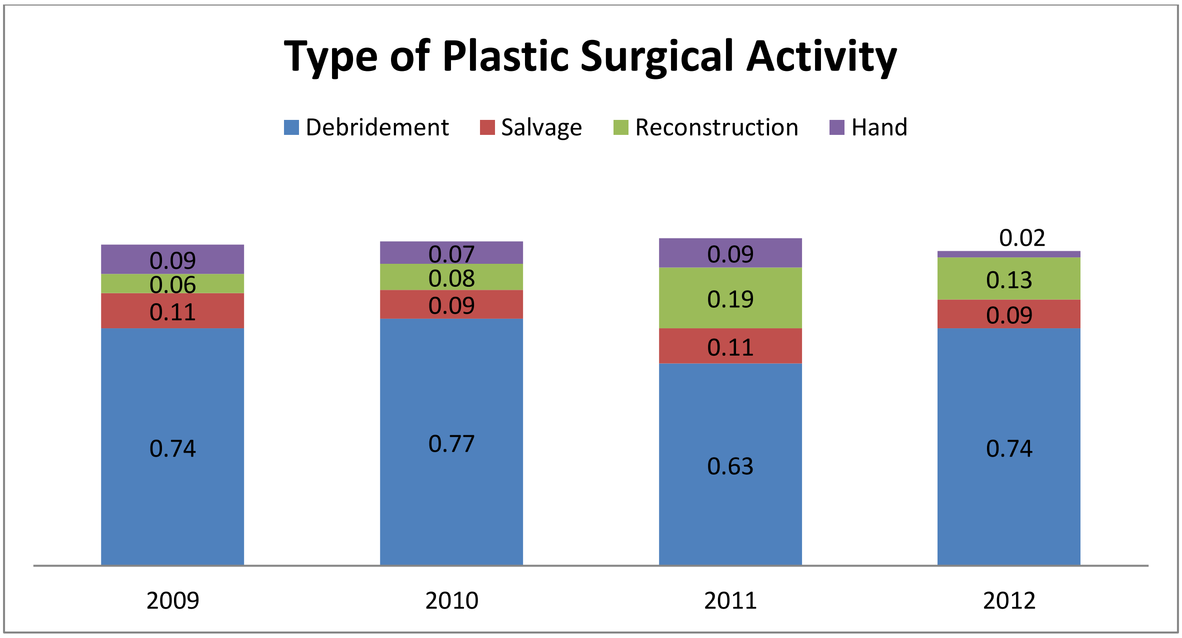


Fig. 4 Percentage of total plastic cases per year cohort: Fig 5: debridement and exploration; salvage (revascularisation and bony stabilisation); reconstructive (Split Skin Graft (SSG), Flap, Nerve reconstruction).

TABLES

Table 1. Activity of the plastic surgeon

	COHORT A 18.05.09 – 10.07.09 1 plastic surgeon	COHORT B 24.12.10 – 19.02.11 1 plastic surgeon	COHORT C 19.02.11 – 18.04.11 2 plastic surgeons	COHORT D 13.07.12 – 23.08.12 2 plastic surgeons	Total
Total surgical cases overall	***307***	***412***	***562***	***373***	***1654***
Total cases involving plastic surgeons (expressed as a percentage of total surgical cases)	*131 (43%)*	*178 (43%)*	*199 (35%)*	*137 (37%)*	***645 (40%)***
Plastic surgeons alone (expressed as a percentage of total cases)	20 (7%)	46 (11%)	84 (15%)	61 (16%)	211 (13%)
Plastic surgeons as part of the multi-surgeon approach (expressed as a percentage of total cases)	*111 (36%)*	*132 (32%)*	*115 (20%)*	*105 (28%)*	***463 (28%)***

Table 1, Plastic cases performed by plastic surgeons alone vs multi-surgeon team were calculated as percentages of total surgical cases for each cohort overall

Table 2 Regions of the body that plastic surgeons operated on

	COHORT A 18.5.09 – 10.7.9	COHORT B 24.12.10 – 19.2.11	COHORT C 19.2.11 – 18.4.11	COHORT D 13.07.12 – 23.08.12	Total
Total Number Trauma Cases Overall	307	412	562	373	1654
Total number cases involving plastic surgeons	**131**	**178**	**199**	**137**	**645**
Total number of body regions operated on overall	**264**	**309**	**344**	**214**	**1131**
RATIO of TRAUMA REGIONS per CASE *Number of operative regions per plastic case (Total number of body regions overall operated on/total number of plastic cases)	2.01	1.73	1.72	1.56	1.75
Total Head and Neck cases	**76 (58%)**	**75 (42%)**	**92 (46%)**	**55 (40%)**	**298 (46%)**
-Head: Face, scalp, head, ear	52 (40%)	61 (34%)	58 (29%)	36 (26%)	207 (32%)
-Eyes	7 (5%)	7 (4%)	28 (14%)	15 (11%)	57 (9%)
-Neck and retropharynx	17 (13%)	7 (4%)	6 (3%)	4 (3%)	34 (5%)
Total Upper Extremity cases	**84 (64%)**	**129 (72%)**	**127 (64%)**	**70 (51%)**	**410 (64%)**
-Upper limb, shoulder	49 (37%)	74 (42%)	62 (31%)	44 (32%)	229 (36%)
-Hand	35 (27%)	55 (31%)	65 (33%)	26 (19%)	181 (28%)
Total Trunk cases	**41 (31%)**	**34 (19%)**	**45 (23%)**	**42 (31%)**	**162 (25%)**
-Torso, thorax, back	12 (9%)	9 (5%)	15 (8%)	12 (9%)	48 (7%)
-Abdomen	19 (15%)	12 (7%)	25 (13%)	19(14%)	75 (12%)
-Pelvis	2 (2%)	3 (2%)	1 (1%)	1 (1%)	7 (1%)
-Perineum, buttock	8 (6%)	10 (6%)	4 (2%)	10 (7%)	32 (5%)
Total Lower Extremity cases	**63 (48%)**	**71 (40%)**	**80 (40%)**	**47 (34%)**	**261 (40%)**
- Lower Limb, hip, groin					

Table 2. total cases per region were calculated as percentage of total surgical cases involving plastic surgeons. *Operative trauma regions per plastic case as calculated for each cohort as the total operative regions per cohort/total plastic cases per cohort and overall (total).

Table 3: Relationship between Fall in International Security Assistance Force Casualty Numbers and Number of Reconstruction Procedures Being performed from 2009-2012+

Year	Total plastics cases	Debridement			Salvage			Reconstruction				Hand
		Debridement	Exploration	Total	Revascularisation *includes unspecified salvage and repair	Bone stabilisation	total	SSG	Flap	Nerve reconstruction	Total	
2009	131	82 (63%)	15 (11%)	74%	6 (5%)	8 (6%)	11%	7 (5%)		1 (1%)	6%	12 (9%)
2010	178	116 (65%)	21 (12%)	77%	12 (7%)	3 (2%)	9%	9 (5%)	3 (2%)	2 (1%)	8%	12 (7%)
2011	199	113 (57%)	12 (6%)	63%	13 (7%)	7 (4%)	11%	24 (12%)	10 (5%)	3 (2%)	19%	17 (9%)
2012	137	97 (70%)	5 (4%)	74%	10 (7%)	4 (3%)	9%	14 (10%)	4 (3%)		13%	3 (2%)

SSG, split skin graft.

+Percentage of total plastic surgery cases that were debridement, salvage, reconstruction, or hand.

Conclusion

The initial work reported above by Maitland et al., (2016), was continued to form the complete database analysed here - 10,891 consecutive surgical cases - spanning, in its entirety, the latter half of the conflict in Afghanistan (2009-2014).

The dataset records the complete surgical activity performed at Camp Bastion (Helmand Province), during different phases of the war including: wounding patterns; surgeons; combat activities; hospital combat mission emphasis, etc.

This data set will enable, for the first time, the comprehensive analysis of the consecutive surgical cases carried out by surgeons from different specialty backgrounds over a 5-year period – the largest combat-related study of its kind to date.

We aim to provide a template of the current surgical skills we believe will best prepare the combat surgeon for future conflicts and/or civilian terror attacks. As such, this thesis aims to provide the evidence that will inform medical planning and enable risk-assessed decision-making processes for Armed Forces Commanders for future conflicts and enhance preparedness for terror related attacks.

Further work is required to cross-reference our findings to the Joint Theatre Trauma Registry (JTTR) and ascertain if any change in outcomes (e.g. wound infection rates, wound healing times, amputation/stump success, functionality and quality of life) was conferred by plastic surgeons being present in such surgical cases. Further analysis of the "Maitland Module" will ascertain whether or not other specialities or team components affect surgical outcomes.

Chapter 2

Introduction

The Armed Forces of the United Kingdom have been actively engaged in combat operations in Afghanistan over the past ten years. One prospective observational study of Royal Navy and Royal Marine personnel deployed during the years 2003-2010 demonstrated a risk of injury, or death, per year of operational service, of 4.6%. One quarter of injured personnel died (Penn-Barwell et al., 2013).

The problem:

The surgical procedures necessary to manage severely injured casualties (e.g. vascular, bone, soft-tissue etc.) has not been systematically, or objectively, examined (Fries and Midwinter 2010; Blackbourne et al., 2011; Ramasamy et al., 2010; Jacobs et al., 2012; Hoencamp et al., 2014; Schwab et al., 2015). A standardisation of surgical-specific requirements for conflict across all three US service and NATO partners does not currently exist (Schwab, 2015; Hoencamp et al., 2014).

Currently, a UK military surgeon's skill set is gained from civilian specialty training and is augmented by supplementary training specific to combat operations e.g. Military Operational Surgical Training (MOST) (DuBose et al., 2012; Ramasamy et al., 2010). One concern, however, is that civilian surgical training does not adequately equip the modern warfare surgeon. Training in definitive trauma care does not currently exist in the UK, and modernisation of surgical careers has tended to shorten surgical training while increasing organ-specific specialisation (Tai et al., 2006; Tai et al., 2008; Tai 2009; Ramasamy et al., 2010). The broad skill set necessary for the safe and efficient surgical management of victims of combat trauma may be compromised as a result of this change. For example, 56.8% of combat surgeons within the United States *did not* feel that their trauma team was adequately prepared (Schwab 2015).

It is unlikely therefore, that a single surgical team can adequately address all Battle Injuries (BI) and Disease Non-Battle-Injuries (DNBI), either as emergency, or non-emergency procedures. Accordingly, in recognition of complex injury patterns encountered in Afghanistan, the traditional model of warfare surgical provision (i.e. a two-man team consisting of General surgeon and a Trauma / Orthopaedic surgeon) was adapted in 2008 to also include a Plastic surgeon (Maitland et al., 2016).

It is evident, that there is a need for the development of a new skill set tailored for the combat surgeon that is generalist in its approach incorporating the skills from a variety of surgical specialisms (Schwab, 2015).

The present study aims to analyse the comprehensive surgical database of cases carried out from 2009 - 2014, the end of formal operations in Afghanistan. In doing so, this study hopes to highlight the areas for further development of surgical training and proposes a template which aims to provide a surgical skills and risk assessment tool for future surgical provision in conflict. We aim to provide a new region-based template for surgical procedures in order to enable surgeons, regardless of surgical backgrounds, treat casualties of war or terror attacks in a remote and austere environment anywhere in the world at any time.

The likelihood however is that the future of emergency surgical care is likely to constitute a broad base of surgical competencies. No single individual, or organisation, is currently accountable for the readiness of surgical provision in future combat operations. We provide evidence for, and prevention of, a "slipping back" (a gradual de-skilling of surgical competence and experience) in surgical readiness between conflicts during peacetime.

The database

Prior to the present study previous data-based studies have been carried out on The Joint Theatre Trauma Registry (JTTR) which was formed in the UK in 2003. It was joined by the USA in 2005. The JTTR recorded all combat injuries sustained by troops while serving in Afghanistan (Owens et al., 2008; Brown et al., 2012). This comprehensive record of the Afghanistan conflict has provided an important detailed source for retrospective analysis. Extensive research has already been done on this registry and has contributed to the improvement of Combat Casualty Care (CCC).

The present study is unique because the database is not injury orientated. Instead, the database is intervention orientated, specifically, in terms of surgical procedures performed. Previous studies using the JTTR to analyse surgical activity, was limited by the number of data-points and narrow time periods analysed. In addition, the JTTR dataset is Emergency Medicine (EM) based and pre-hospital care focused. It is therefore limited in its scope and in its ability to characterise the surgical interventions performed or the continuum of care required for the combat casualties for future conflicts.

The present study analyses 10,891 consecutive surgical cases stretching from 2009 to the end of formal operations in Afghanistan, 2014 - some 20,266 surgical procedures.

The database is a consecutive catalogue of all the surgical cases and procedures carried out on civilians (incl. paediatric) and combatants during the course of the conflict. The database incorporates Battle Injuries (BI) and DNBIs, as well as primary (first surgical case presentation), and secondary "take-back" (subsequent follow-up surgeries on the same casualty), cases. The present study will extend, and bring up-to-date the surgical skill set suggested by Ramasamy et al., 2010. It will also provide a baseline standardisation of the surgical procedures for future combat surgeons across NATO countries.

Main Aims and Objectives:

The present study aims (see thesis outline) to improve working practices by examining the surgical procedures that have been employed to manage injured casualties during the last five years of armed conflict in Afghanistan. We anticipate this objective assessment will inform surgical provision and allow novel approaches to surgical management in future conflicts and terror attacks.

Specific Study Objectives:

It is anticipated that the database may provide the much-needed evidence to prevent the "slipping- back" in expertise gained over the last ten years in trauma surgery training and skill sets during peacetime (a gradual de-skilling of surgical competence and experience). We hope to lessen the steep learning curve typically experienced by surgeons at the start of conflicts and in turn, reducing the potential loss of life caused by the dip in readiness that prevails during peace-time when surgeons return to civilian training, practice and medicine (Schwab 2015).

The influence of current UK higher surgical training on the provision of surgery in conflict:

The incremental gains in survival during the conflict in Afghanistan have led to an overall success story of Combat Casualty Care (CCC). Casualties can now survive previously non-survivable wounds and the reasons for this improvement are currently undefined, but are likely to be multifactorial (Butler and Blackbourne 2012; Eastridge et al., 2012; Palm et al., 2012; Penn-Barwell et al., 2015).

One factor is the deliberate process of performance improvement by the UK Defence Medical Services (DMS). The Armed Forces currently delivers healthcare within the following key roles [see Allied joint medical doctrine for medical support (AJP-4.10, B)], as follows:

- Role 1+2 Pre-hospital Care: The UK provision of 'Prolonged Field Care' (PFC) enables casualties to go from Point of Wounding (POW) on the battlefield, through basic Medical Treatment Facilities (MTF) close to the front-line (roles 1 and 2).

  Past research focused on life-saving interventions at these pre-hospital stages e.g. complex airway management and blood transfusions (Borgman, 2007), which lead to significant advances in Damage Control Resuscitation (DCR). Throughout the duration of the present study (2009-2014), The UK Medical Emergency Response Team (MERT), acted as a bridge between role 1 and 3 (Bilski et al., 2003) which decreased the length of time required to provide these life-saving interventions.

- Role 3: is a resource rich, static, advanced facility, where surgeons perform life- and limb-saving operations e.g. Camp Bastion, Afghanistan.

  There is a paucity of peer-reviewed evidence on the surgical interventions performed at Role 3 (Fries and Midwinter 2010; Blackbourne et al., 2011).
  It is the surgical activity carried out at role 3 that forms the focus of the present study.

- Role 4+5: repatriated Armed Forces personnel progress rearwards to their host nation or allies for further surgical management, reconstruction, rehabilitation, and ultimate return to work, or discharge from the Armed Forces (Blackbourne et al., 2012a).

A range of surgical activities occurred at the Role 3 Camp Bastion facility. These included cases of: Battle Injuries (BI) and Disease and Non- Battle Injuries (DNBI). Both BI and DNBI involved combatant Afghan National Security Forces (ANSF); International Security

Assistance Forces (ISAF); and civilian adult (including Interpreters) and civilian paediatric cases (Humanitarian).

1. Battle injuries (BI):

Most battle injuries (BI) in conflict are caused by blasts as opposed to civilian practice where blunt trauma predominates. The battle injuries caused by blasts/explosions that generate fragments/shrapnel which lead to high-energy-transfer penetrating trauma, known as blast trauma. The conflict in Afghanistan was typified by the Improvised Explosive Device (IED), to which most of the blast trauma was attributed (Breeze et al., 2011). However, previous analyses, at various stages of the conflict in Afghanistan, confirm that despite the use of IEDs the overall mechanism of injury remained similar to previous conflicts, that of blast (Owens et al., 2008; Ramasamy et al., 2009).

The IED injuries are unique however, in their multiplicity and severity, presenting specific challenges to the surgeon. Three areas in particular caused difficulties to the surgeon. Firstly, extremity injuries were more frequent and more severe – typically resulting in multiple traumatic amputations compared to previous conflicts (Krueger et al., 2012; Potter, 2006; Jacobs, 2012). Secondly, the associated vascular injuries occurred at a higher rate in Afghanistan than in previous conflicts (Stannard et al., 2011; White et al., 2011; Clouse et al., 2007). Thirdly, when severed, the elastic nature of these major vessels, and especially arteries, caused them to retract into the chest or abdominal cavity. When this happens, it is sometimes necessary to retrieve the vessel. This may then involve efforts to tackle the bleeding on difficult-to-access major vessels (e.g. the left subclavian artery). The surgeon may have little experience operating on such unfamiliar and "non-compressible" areas of trauma. Such bleeding deep into "junctional" areas e.g. the neck/groin/axilla, may necessitate opening the abdomen and / or chest to gain definitive vascular control proximal to the injury itself (Jacobs et al., 2012).

Some of the injuries treated in Afghanistan might have been encountered before in civilian surgical practice (Dubose et al., 2012). Many decisions, however were often made by surgeons with insufficient vascular and cardiothoracic training (Blackbourne et al., 2012a). In a recent study of "general" surgical consultants, only a third felt prepared to manage cardiothoracic injuries (Ramasamy et al., 2010). A survey of US non-fellowship trained General Surgeons reported that surgeons wanted more thoracic and mediastinal injury management training (Schwab 2015). That being said, inroads have been made into the development of non-surgical interventions to mitigate against haemorrhage from junctional areas of the body during Roles 1 and 2 (Blackbourne et al., 2008; Blackbourne et al., 2010; Blackbourne et al., 2012b). Such as, Damage Control Resuscitation (DCR) techniques (careful hypotensive resuscitation to temporise the triad of coagulopathy, acidosis and hypothermia which permeates until the source of haemorrhage can be controlled; Holcomb et al., 2007). Other non-surgical techniques to control bleeding include, Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) which has been shown to be a viable alternative to resuscitative thoracotomy as an anatomical and physiological stabilisation tool for non-compressible haemorrhage (Gamberini et al., 2017).

The term "polytrauma" is often used to describe the extensive injury pattern caused by IEDs, but there is a lack of international consensus on the definition of injury severity (Butcher and Balogh, 2011). To aid surgical decision making, and in recognition of complex lower limb injuries from IEDs, The Bastion Classifications system of extremity injury was developed (2010-2011) and included the associated injuries and vascular control requirements (Jacobs et al., 2012).

An overall injury severity score must remain broad enough to encompass the range of injuries sustained in a modern conflict zone. To date, anatomical regions are used to classify injury severity with the Injury Severity Score (ISS) and Abbreviated Injury Severity (AIS) as examples (Champion et al., 2010). The Red Cross Wound Classification (RCWC) includes associated injury to major vessels, or viscera (Ramasamy et al., 2009). Over the course of the conflict in Afghanistan mortality fell significantly relative to the ISS (Rasmussen et al., 2013). However, it is clear that surgical decision making, around the polytrauma nature of modern conflict care wounds, is made more complicated by the existence of several wound classification systems without international consensus.

Bleeding is the primary cause of death in conflict, and so, whilst the mechanism of injury may change in future kinetic armed conflicts, the multiplicity of injuries caused by explosions, and the surgical interventions required to manage these, are likely to remain the same (Pannell 2011; Eastridge et al., 2012).

The present study aims, therefore, to analyse the consecutive surgical cases carried out in Afghanistan in order to ascertain the surgical requirements for future conflicts.

2. Disease and Non-Battle Injuries (DNBI):

In addition to BI-related surgery, conflict zone surgeons are also required to perform emergency operations, similar to civilian duties, on a range of Disease and Non-Battle injuries such as burns, or mangled extremities from car crashes, etc. (Parker, 2000). There are few peer-reviewed studies on the DNBI surgical procedures performed on local populations (Humanitarian: CIV; PAED; ANSF), and allied troops (ISAF). Previous studies report that DNBI surgery was made up of mainly Incision and Drainage (I&D) of abscesses which accounted for 3.8% of cases (2006-2008) and 2.6% of procedures during 2008-2010 (Jacobs et al., 2012).

The present study aims to quantify the DNBI burden of all casualties (ANSF, CF, LN) on combat surgeons in conflict zones.

3. Humanitarian:

After the explosion of an IED, those in the vicinity (CIV; PAED) with severe battle-injuries (BI) may require essential operations that prepare them to return to their local environment where healthcare and long-term rehabilitation, or follow-up care, is limited or non-existent. It is yet to be defined how the surgical procedures carried out on the affected population contribute to, or change, the surgical skill set requirement for conflict zones (Charnley, 2003; Ramasamy et al., 2010). It is possible that definitive procedures like plastic reconstruction (ordinarily reserved for post-evacuation) were performed at a higher frequency in Afghanistan on the humanitarian casualties in recognition of the diminished healthcare options casualties may have had thereafter (Maitland et al., 2016).

Non-government aid organisations (NGOs) traditionally support host nation facilities and combat surgeons when deployed to war-torn/conflict regions (Ramasamy et al., 2010). As the nature of modern conflict changes to include peace-keeping operations, e.g. Syria, a possible scenario is that surgeons might find themselves performing specialist surgical interventions on paediatric conditions, for example, for which the combat surgeon may have no prior experience (Schwab, 2015).

Ramasamy et al., (2010) reported that paediatric casualties (between; 2006-2008 at Role 3), accounted for 14.7% of 1668 surgical cases, a figure overall higher than for the Iraq conflict. Another study found that paediatric trauma (blast, penetrating, blunt or burn) accounted for 5.8% of all admissions, and that the mortality rate was higher in the paediatric group than in the adult civilian or coalition forces (Borgman, 2012). In addition, casualties amongst female combatants, and civilians, occur in conflict and require specific obstetric and gynaecological surgical procedures. The surgical burden of these casualties is yet to be evaluated. This information is required in order to outline definitively the surgical procedures needed for future conflicts, and to aid readiness for potential future terror attacks.

Additional surgical considerations important to the current study come from the experience of NGOs and other countries' Armed Forces operating in conflict zones. For example, the experience of the International Committee of the Red Cross (ICRC) with antipersonnel mines indicates that the surgical decision to amputate, or salvage limbs is often underestimated (Coupland, 1991). Sometimes cultural and religious issues come into play. For example, amputation may be unacceptable within certain cultures and therefore consideration of additional surgical care provision for civilians and combatants may need to be taken into account (Coupland, 1991).

A recent study into the Syrian Civil Conflict since 2011, looked at the surgical care provided to injured civilians at the Israeli border by the Israeli Defence Forces (IDF). The study describes the components of surgical intervention as incorporating pre-hospital; humanitarian; civilian and combatant care (Benov et al., 2014). Abdominal and thoracic injuries i.e. "truncal injuries" were the most frequently treated region in the study (Benov et al., 2014; Rasmussen 2013). It is important to note here that the study went on to highlight that their results may have been biased giving the suggestion that civilian survivors were naturally selected with less severely injured casualties reaching surgical care, while more severely injured casualties were dying in the attempt to do so (Benov et al., 2014; Rasmussen, 2013).

Further to the above, some studies suggest that injured civilians treated by Camp Bastion, Afghanistan, may also have been less severely injured, since again, those with more severe injuries may have died en-route (Coupland 1991; Benov et al., 2013; Tai et al., 2008). The present study aims to calculate the surgical case fatality rate in Afghanistan to understand if there were other demographic differences to be considered.

Current thinking on surgical skill sets for conflict:

Current surgical training in the UK is specialist delivered and organ specific e.g. hepatobiliary, and colorectal surgery, etc. However, the move to subspecialty training means that surgeons in the UK have as little as two years of basic general surgical experience, followed by six years training wholly in their chosen surgical specialty (Ramasamy et al., 2010).

A concern already mentioned is that no individual surgeon, or surgical speciality, can do the full complement of surgical procedures mentioned so far, and if they could they would tire rapidly (Ramasamy et al., 2010). A 2008 survey in the United States recorded that only 18% of trauma centres felt that their surgeons could perform the full complement of surgical procedures (vascular, thoracic, and abdominal). This becomes a major concern in war-time when surgeons in small teams find themselves far forward, with limited kit and equipment, and prolonged casualty evacuation timelines.

This emphasises the need for increased skill set synergism between surgical specialties (Ramasamy et al., 2010; Jacobs et al., 2011). Parker (2008) suggests a team solution to this problem, bringing together individuals from different specialty backgrounds. In Afghanistan, Armed Forces surgeons in training (registrar level) were deployed for six weeks under the mentorship of a senior Armed Forces surgeon to Role 3. This increase in exposure is equivalent to three years UK training (Ramasamy et al., 2010).

In light of this, the pre-deployment Military Operational Surgical Training MOST course in the UK was developed to enhance team training and exposure to potential scenes and surgical scenarios most likely to be faced in conflict zones. In the US however, just 40% attended surgical training courses tailored before deployment and the current consensus is that surgeons felt underprepared (Tyler et al., 2012; Schwab, 2015). As many as 56.8% US surgeons surveyed said that they did not feel the surgical trauma team was adequately prepared and 47.4% believed that the operative team was not adequately prepared (Schwab, 2015).

The present study aims to build on these previous studies by analysing the database (the comprehensive surgical case and procedural catalogue taken from the surgical log-books, Afghanistan 2009-2014). In addition, this study aims to itemise the surgical procedures performed by anatomical region instead of by surgical specialty as per previous studies.

The present study aims to establish the BI, DNBI and Humanitarian surgical procedural burden experienced in Afghanistan so that the template for surgical procedures for anticipated future conflicts can be consolidated and sustained within the civilian surgical paradigm. This becomes increasingly relevant given the increased threat from terrorists on home soils (Moran et al., 2017; BBC News, 2017).

Body regions affected by conflict - our knowledge so far

Changes in medical care are also driven by changes in technology, either by developments in Personal Protective Equipment (PPE); the enemy's enhanced weapon efficiency; or medical technical advancements in healthcare. As the enemy develops more effective weapons, injury patterns change, and surgical interventions must adapt accordingly.

Coupland (1999), described the factors that improve the efficiency of weapons, in relation to antipersonnel mines: firstly, improved destructive force of weapons (fragments that maim civilians and combatants alike and that can be left behind underground for years); and secondly, increased distance between the assailant and the victim (Coupland 1999). Over the course of the conflicts in Iraq and Afghanistan, the phases of battle and kinetics advanced as follows: fast movement of troops at the start of the invasion; stationary conflict with explosives, snipers, and bombs; followed by "explosions" primarily caused by Improvised Explosive Devices (IED) (along with landmines, mortar or shrapnel and grenades) (Owens 2008).

No one can predict what advances there will be in these areas for future conflicts, but the present study aims to consolidate the surgical procedures that took place in our most recent modern conflict, in Afghanistan. In doing so, the present study aims to prepare/set the standard for surgical practice in future conflicts.

Because personal protective equipment (PPE) alters the way that energy is coupled to the body, it protects certain areas of the body better than others from fragmentation injury (Champion et al., 2010). The aim of governments during the conflict in Afghanistan was to reduce the death rate through improved PPE and Combat Casualty Care (CCC) (Eastridge, 2006). Areas not protected by PPE show increasing frequency of injuries.

A brief outline of body regions vulnerable to injury (Holcomb, 2007) (Tai et al., 2008) is outlined as follows:

In conflict people die primarily of haemorrhage otherwise known as exsanguination (Pannell 2011). Analysis of preventable deaths in Afghanistan showed that approximately 40% were from truncal injuries and 20% from head injuries (Pannell, 2011; Neff, 2013). Compared to previous conflicts, there was a significant increase in head and neck wounds, and a decrease in thoracic wounds (Bilski 2003; Owens et al., 2008; Chan et al., 2012). The Canadian surgical experience in Afghanistan (2006-2009) reported a similarly low requirement for thoracic operations, and most frequent operations were on soft tissue and extremities (Brisebois 2011). Truncal haemorrhage (including thorax, abdomen and pelvis) however, accounted for the majority of preventable deaths, as mentioned above (Eastridge et al., 2012). The nature of junctional injuries (axilla, groin and neck) means that they are non-compressible and require surgery within the adjacent cavities to stop the bleeding (Eastridge et al., 2012).

With regard to head injuries, Dubose et al., (2011), found that military Traumatic Brain Injury (TBI) patients had increased survival rates when compared to civilians with TBI, and that military patients were more likely to have invasive monitoring and neurosurgical intervention (Blackbourne et al., 2012).

Other regions of the body exposed to injury include the face, which is injured in 33% of all UK injured servicemen (2005-2009) (Breeze et al., 2012). There is currently no agreed method of describing the location of civilian or military penetrating facial wounds (Breeze et al., 2012). Injuries to the face include: eyes from dust/debris/fragments; and lower jaw/mandibular fractures (Coupland 1991; Owens 2008). Current classification of the face into thirds apportions a high frequency of mandibular fractures as “lower third” injuries, but this description bears no relation to the position of any overlying skin wounds (Breeze et al., 2012). The mandibular injuries seen in conflict (blast) differ to those seen in civilian trauma (blunt), which alters fracture patterns (Breeze, 2011). In combat-induced maxillofacial fractures, maxillofacial surgeons who were not typically deployed as part of the surgical team, showed colleagues how to perform Intermaxillary Fixation (IMF) at Role 3. The reason for this handover of skills across surgical specialties was to reduce the pain during patient transfer and enable definitive treatment at Role 4 where maxillofacial surgeons were based and were able to perform definitive care (e.g. open reduction and rigid internal fixation of mandibular fractures) (Breeze, 2011).

Another unique area of the body vulnerable to injury is the gluteal region (buttock). Gluteal injuries are associated with injuries to pelvic and abdominal organs, vessels and rectum. At present, a standard for triage and evaluation of gluteal injuries does not exist and, consequently, unnecessarily poor outcomes can occur (DiGiacomo et al., 1994; Lesperance et al., 2008). Glasgow et al., (2012) found that military casualties with colon or rectal trauma suffered elevated mortality rates. However, interventions such as fecal diversion were less frequently carried out in Afghanistan than Iraq, but those that did have fecal diversion had lower mortality rates (Glasgow, 2012).

Improvements in medical technology throughout the conflict in Afghanistan, such as use of the CT scanner, led to changes in surgical care delivery. For example, in a study of UK personnel injured in Afghanistan, it was documented that laparotomy procedures decreased, and non-operative management of injuries to the abdomen increased (Morrison et al., 2012). In addition, some low-energy-abdominal-penetrating trauma cases were managed with the use of conservative laparoscopic surgical techniques (Blackbourne et al., 2012).

Despite all advances made, casualties surviving up to Role 3 and Role 4 still went on to develop multi-organ failure (MOF) and, or, sepsis. This is a key area for further development. Technology improvements in this area, so far, have included advances in organ support e.g. development of Extracorporeal Membrane Oxygenation (ECMO) in prevention of MOF (Neff, 2013).

Nessen et al., (2009) found that there was no difference in mortality between those casualties discharged from Role 3 centres back into the Afghani community compared to those repatriated to United States (United States Forces USF) and subsequently discharged from Role 4 facilities there. Therefore, the surgical interventions carried out at this stage in the patient journey clearly had a significant impact on post-operative survival.

Therefore, the present study aims to analyse the surgical interventions carried out at Role 3 Afghanistan in order to assess the positive impact of the surgical interventions on patient outcome. It also aims to turn the focus away from injury patterns and surgical specialisms. Instead, the categorisation of surgical procedures by anatomical region aims to account for the multiplicity of wounding associated with blast trauma in order to ascertain the comprehensive surgical requirement for war and terror attacks.

The reason why this study is needed:

I performed a comprehensive review of the available literature (scope search) to identify similar studies, and any additional surgical databases relevant to this thesis.

I used the following search terms: [(surgery OR surgical OR surgical training) AND (procedure OR procedures OR skill set OR intervention OR interventions) AND (Afghanistan) AND (Role 3) AND (military)].

The databases MEDLINE and EMBASE were continuously searched up until the week ending 23 Sept 2018 using the Ovid interface. All searches were limited to human studies only.

The scope search generated 41 studies, of which 11 were duplicates, and 29 were not suitable (medical, data specific to surgical speciality, Role 2 data, or the study years did not overlap with the present thesis).

The scope search identified 1 suitable study available for comparison to the current database (Jacobs et al., 2012). This, combined with a thorough search, using direct terminology of PubMed and The Cochrane Database of Systematic Reviews, also identified Ramasamy et al., (2010) for comparison to the thesis database.

Ramasamy et al., (2010) classified the surgical procedures carried out in a two-year period (1668 surgical cases) by surgical speciality, and Schwab (2015) commented that it matched the American experiences (Ramasamy et al., 2010; Jacobs et al., 2012; Schwab, 2015). Based on this, a previous surgical skill set proposed by Parker, (2008) was adapted, and procedures were broken down into the following surgical specialties: orthopaedic; thoracic; abdominal and neurosurgery. However, it currently remains that the comprehensive evidence based surgical skill set requirement for armed conflict is yet to be defined, and there remains no current international agreement on the skill set required for war (Schwab, 2015).

A standardisation of surgical intervention requirements for conflict does not currently exist (Dubose et al., 2012; Hoencamp et al., 2014; Schwab 2015) and we are at the end of ten years of conflict in Afghanistan. The surgical experience gained in Afghanistan is fading, and a "slipping back" (a gradual de-skilling of surgical competence and experience) in peace-time is likely to have already occurred. We aim to assess the relationship between surgical experience and outcomes such as case fatality and operation length.

Blast trauma does not respect anatomical boundaries, or fall neatly into the surgical specialties. We aim to develop a new anatomical approach to trauma surgery in order to account for the poly-trauma nature of wounding from explosions, and to develop a template for surgical procedures to improve readiness for future conflicts and terror attacks.

Impact:

The relevance of this study is to provide much needed, vital information to the surgical community, and Armed Forces Commanders, to prepare the surgeon for future conflicts or terror attacks occurring during relative peacetime (Moran et al., 2017; Smith et al., 2017). The study aims to optimise surgical planning and risk-management, training, research and resource allocations (Owens et al., 2008). The study therefore has wide-ranging implications and the potential for changing policy.

Chapter 3

Methods

Introduction to the database

The database consists of 18 original surgical theatre log-books containing records of all consecutive surgical cases performed in Afghanistan, Role 3 Camp Bastion Facility between 2009 and 2014 (a total of 10,891 surgical cases and 20,266 surgical procedures). The database therefore constitutes a complete record of all surgical cases until the end of formal operations in Afghanistan in September 2014. For comparison and contribution to the Joint Theatre Trauma Registry (JTTR) see Figure 1.

The handwritten surgical logbooks were manually transcribed directly into an excel spreadsheet for analysis. Each row is assigned a number 1-10,891, these are the cases. This process was carried out over many hours (5 mins per case).

In addition to the standalone database of sequential surgical interventions performed in Afghanistan, some additional data were re-coded during entry and summarised into additional fields for additional analysis. For example, primary and secondary surgical case categorisation (see Appendix 3a and 3b).

Each surgical case was assigned to a specific body region (see itemisation of data sub-section of materials and methods). The other columns were as described in Methods: itemisation of data sub-section:

The database for the present study details casualty demographics surgically treated as follows: Afghan National Security Forces (ANSF) (Afghan National Army; Afghan National Police) civilians (CIV), paediatric (PAED), females, elderly, contractors, and interpreters (INTERP)) as well as Enemy Forces (EF). It therefore includes all BI; DNBI; and Humanitarian-related operations performed and further categorised as primary (first surgical case), or secondary "take-back" (all subsequent surgical cases on the same casualty).

The origin of casualties was determined by nationality of cases. This was incomplete in some areas (see methodologies for chapters 4,5,6, and 7). These data were used as a proxy to examine any difference in surgical activity for a population that was wearing protective body armour (ISAF) and that did not (CIV; PAED; INTERP; EF). Within the ANSF population their usage of body armour and helmets varied, and as a result this population was excluded from some analyses (see methodologies for chapters 4,5,6, and 7).

Primary cases detail the initial surgical interventions performed to stabilise the patient in the context of Damage Control Surgery (DCS), but also important DNBI cases such as caesarean, testicular torsion, and ruptured ulcers. Secondary cases highlight surgical cases carried out thereafter i.e. take-back surgical cases performed on the same casualty, and also included surgical procedures e.g. to remove or change dressings, or to refashion stumps, etc. The anatomical region these surgical procedures was not always recorded (see methodologies for chapters 4,5,6, and 7).

The length of each operation is recorded in minutes. The time in, and out, of theatre was recorded using conventional local time 24-hour clock format.

In addition to the demographics which included the nationalities and ages of surgical cases (where documented), the individual surgical cases were categorised by mechanism of injury [BLAST incl. IED, Mortar, Grenade; Gun Shot Wound (GSW); BURNS incl. Acid and chemical attacks; and Stabbing; DNBI (Disease Non-Battle Injury) that incl. Road Traffic Accidents (RTAs) and Bites]; the requirement, or not, of proximal control for bleeding associated with non-compressible haemorrhage.

The database columns in addition to the above include: the names and numbers of surgeons per case, the anaesthetist/s name/s and any additional anaesthetic notes incl. blocks; Rapid Sequence Induction (RSI) and sedative techniques), extra kit/equipment used (e.g. Negative Pressure Wound Treatment (NPWT) dressings, drains etc), any additional comments, Died On the Table (DOT/Died of Wounds DOW) and time of death (where recorded), operating table number, hospital number, serial number, cohort number (log book number) (see Itemisation of data subsection of materials and methods for further details).

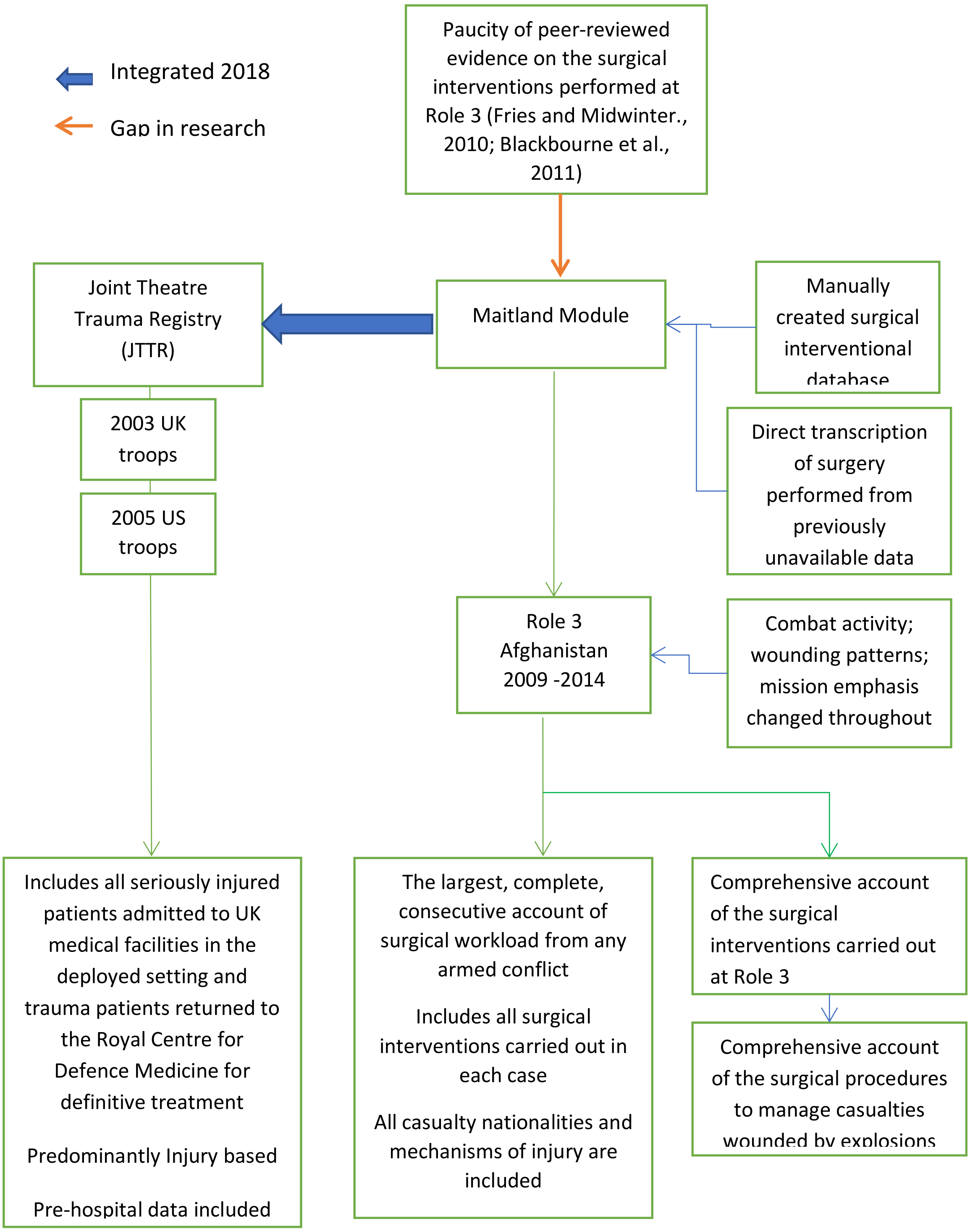
Note: Surgeon names and other personal identifiers are used for analytical purposes only and are not used anywhere in this thesis in order to protect the individuals concerned

<u>Analysis</u>

The database formed the basis of the present study's research and was analysed as follows: As data was inputted into the Microsoft Excel Spreadsheet we created a separate document of all the key search terms used to facilitate the comprehensive interrogation of the database. Key search terms also comprehensively catalogued anatomical details and surgical procedures. This document can be made available on request.

For itemisation of data see Appendix 3c.

Figure 1: Maitland Module - comparison and contribution to the Joint Theatre Trauma Registry (JTTR)



Chapter 4

Classification of surgical procedures in armed conflict: an analysis of 10,891 consecutive surgical cases Afghanistan, 2009-2014

I - Introduction and Overview

Abstract

Background:

There is an acknowledged paucity of peer-reviewed evidence on the surgical procedures performed in conflict. This study analyses 10,891 surgical cases performed by NATO surgical teams in the Role 3 Camp Bastion Facility during the Afghanistan conflict, between 2009 and 2014, making it the largest, consecutive surgical database to come from any modern conflict to date. We describe the results for the first time and highlight key differences to previous research in this area.

Methods:

The database includes all the surgical cases (n=10,891) performed in the latter half (5 years) of the conflict until 2014, the end of UK formal operations in Afghanistan. To aid comparison to previous studies and for the present study, the methodology was kept as similar as possible to previous studies. The combat activity, wounding patterns, surgeons and mission emphasis of the hospital, changed throughout the years of the conflict studied. Statistical analysis with z-test was used to compare population proportions between our results to previous studies throughout. Significance was accepted at the 5% level ($p<0.05$).

Results:

The surgical workload was significantly increased than in previous studies in the following key areas: eye surgery 3.8% of surgical cases (n=414 of 10,891), and 2% of surgical procedures carried out were eye related which is a significant increase to eye-related injuries reported by Jacobs et al., (2012) (2% vs. <1%; $z=-5.058$; $p<0.001$). We show a significant increase in vascular procedural workload, and that vascular procedures took place in 4.9% of operations (n=990 of 20,266) or a four-fold increase compared to previous findings (Ramasamy et al., 2010) (Table 1: 4.9% vs. 1.1%; $z=-8.160$; $p<0.001$). Vascular procedures to gain proximal vascular control, a Damage Control (DC) procedure, were performed in 3.3% of cases (n=360

of 10,891). Laparotomies accounted for 8.0% of total surgical procedures (Table 1: n=1624 of n=20,266), significantly increased from previous analyses (Ramasamy et al., 2010; Jacobs et al., 2012) (8.0% vs. 4.8%; z=-5.363; $p<0.000$ and 8.0% vs. 9.1%; z=2.675; $p<0.001$). The present study shows that amputation procedures occurred in 8.5% of total surgical procedures (Table 1: n=1723 of 20,266), significantly more than previous years of the conflict (Ramasamy et al., 2010) (8.5% vs. 3.8%; z=-7.717; $p<0.001$). For the first time we show that 28.5% of all amputations were bilateral (n=492 of 1723).

Of the total cases, 19.9% underwent Negative Pressure Wound Treatment (NPWT) (n=2167 of 10,891) or 10.7% of surgical procedural workload (n=2167 of 20,266).

Emergency Disease Non-Battle Injury (DNBI) was significantly more prevalent than previously described and accounted for 14.4% of primary surgery (n=811 of 5632). We show a significant increase in DNBI surgical workload (7.4%) compared to previous years of the conflict (Ramasamy et al., 2010) (7.4% vs. 4%; z=-5.085; $p<0.001$).

Cases that required >300 minutes of continuous surgical time: represented 2.8% (n=303 of 10,891) and of these 76.2% were primary trauma surgery for casualties suffering blast or GSW (n=231 of 303) and 2% of case fatalities were in this group (DOW >300 minutes n=2 of 95). Proximal Vascular Control procedures were required in 24.1% of cases >300mins long (n=73 of 303) and 14.2% required Abdominal Cavity (AC) surgery to gain proximal vascular control (n=43 of 303), one of whom DOW.

Of the 20,266 procedures analysed, a significantly greater proportion of cases were performed "out-of-hours" (51.3% performed between 1800-0800 hours local time) than previously described (Table 2: 51.3% vs. 28%; z=-17.735; $p<0.001$). For the first time we show that secondary surgery accounted for 48.2% of cases and presents a significant surgical workload. Surgical case fatality rate, Died of Wounds (DOW), was 96 per 10,891 surgical cases. Blast trauma accounted for 55.7% of primary Battle Injuries (BI) surgery (n=3136; of 5632) and 51.1% of casualties who DOW suffered blast injury (n=49 of 95).

<u>Conclusions:</u>

This study illustrates the significance of the database as it fills a much-needed gap in our knowledge of the surgical procedures carried out in war. There were significant differences between findings from my database and previous classifications of surgery carried out in Afghanistan. We show, therefore, that the suggested surgical skill sets previous studies proposed, are not the full account. We highlight that the surgical skill sets required for war are yet to be defined, or internationally agreed. This study illustrates the significance of the thesis database as it fills a much-needed gap in our knowledge of the detailed surgical procedures carried out in war.

Introduction

The challenge, as described by C Schwab, 2015, is to:

"Develop a new type of trauma surgeon: military surgeon and combat designated (the combat surgeon), with a very broad skill set and competencies demanded on the battlefield and for the humanitarian mission of military surgery."

***The Winds of War* (Schwab, 2015)**

The present study analyses 10,891 consecutive surgical cases stretching from November 2009 until the closure of the hospital facility, Camp Bastion, Afghanistan September 2014- the official end of operations in Afghanistan. The database is a contemporaneous electronic surgical log-book made up of all the surgical procedures carried out case-by-case on civilian adults (CIV), paediatric casualties (PAED) and combatants alike [(International Security Assistance Forces (ISAF), Afghan National Security Forces (ANSF), and Enemy Forces (EF)] throughout the conflict.

The database is unique in its size, consecutive nature and that it is intervention-based (focusing on what surgery took place), unlike the injury-based databases that have gone before. The Joint Theatre Trauma Registry (JTTR), formed in the UK (2003) and in the USA (2005) recorded all combat injuries sustained by troops while serving in Afghanistan (Owens et al., 2008; Brown et al., 2012). The present database will be integrated fully into the JTTR.

Extensive research has already been done on the JTTR registry (as it currently stands prior to the inclusion of the present study) to improve Combat Casualty Care (CCC) over the course of the conflict and has enabled poly-trauma casualties to survive previously non-survivable injuries (Palm et al., 2012; Butler and Blackbourne, 2012; Eastridge et al., 2012; Butcher and Balogh, 2011). There is, however a scarcity of peer-reviewed evidence on the surgical interventions performed in conflict (Fries and Midwinter 2010; Blackbourne et al., 2011; Schwab, 2015).

The growing concern is that civilian surgical training does not adequately equip the modern warfare surgeon, as training in definitive trauma care does not currently exist in the UK (Ramasamy et al., 2010; Smith et al., 2017). Modernisation of surgical careers has shortened surgical training and increased organ-specific specialisation (Ramasamy et al., 2010; Tai et al., 2006; Tai et al., 2008; Tai, 2009). Currently, UK military surgeons' competencies are based on civilian specialty training and is augmented by supplementary training specific to combat operations e.g. the Military Operational Surgical Training (MOST) course (DuBose et al., 2012; Ramasamy et al., 2010).

It is recognised that the traditional two-surgeon team (orthopaedic and general surgeon) is unlikely to be able to perform the full complement of surgical skills necessary for the safe and efficient surgical management of victims of combat trauma (Jacobs et al., 2012). This, in turn, may be compromised as a result of the gradual subspecialisation of surgical training that sees 47.4% of Eastern Association for Surgery of Trauma respondents report that they did not feel the surgical team was adequately prepared (Schwab, 2015).

The surgical procedures necessary to manage the severely injured in modern conflict (e.g. vascular, bone, soft-tissue, etc.) has not been systematically and objectively examined. There is currently no international agreement on what the broad surgical procedures required for war are (Schwab, 2015).

Previous studies from Afghanistan have classified surgical procedures by specialty. Ramasamy et al., (2010), and subsequently Jacobs et al., (2012) analysed two separate year periods at Camp Bastion, Afghanistan (an analysis of 1668 cases and 4276 cases respectively). Schwab, (2015) commented that the description of surgical activity described by Ramasamy et al., 2010 affirmed the American experience.

The present study aims to classify the surgery carried out in our most recent modern conflict and, through comparison to previous studies in this area, suggest further research to establish ultimate more comprehensive surgical template for war.

Methods

Study Design

We summarise the surgical workload over a 5-year period at Role 3 Camp Bastion Facility, Afghanistan by NATO surgical teams and provide an overview analysis of the largest data set from modern conflict: 10,891 consecutive surgical cases performed by NATO surgical teams, during 2009 and 2014, as well as a comparison to previous periods of the conflict (Ramasamy et al., 2010; Jacobs et al., 2012).

During 2009-2014 the combat activity, wounding patterns, surgeons and mission emphasis of the hospital, changed throughout the years of the conflict studied. Therefore, the present study is representative of the overall workload.

From November 5, 2009, to September 21, 2014, we entered, sequentially, all written entries in operating theatre records (n=10,891) (18 original handwritten surgical theatre log-books) into an Excel (Microsoft corporation) spreadsheet for analysis (each row is assigned a number 1-10,891 these are the cases; for further details see Chapter 3 – database). The database therefore constitutes a complete record of all surgical cases until the end of UK formal operations in Afghanistan in September 2014.

The database will be incorporated into the JTTR Joint Theatre Trauma Registry for validation. The personal surgical logbooks of plastic surgeons were briefly analysed to validate the results of the theatre logbooks and were subsequently published (Maitland et al., 2015; and are presented in Chapter 1).

Data Collection

In addition to the demographics which included the nationalities and ages of surgical cases (where documented), the individual surgical cases are categorised by the mechanism of injury, and are classified as: Battle Injury (BI): Gun Shot Wound (GSW), Burns (incl. Acid and chemical attacks), Blast i.e. explosion (incl. IED, Mortar, Grenade); Stabbing; and Disease Non-Battle Injury [DNBI that incl. Road Traffic Accidents (RTAs) and Bites].

The date and time of surgery was recorded chronologically as case start and finish time. The length of each operation is detailed in minutes. The time in and out of theatre was recorded as local time using the conventional 24-hour clock format.

The emergency status of the case was documented along with operation type: primary (first-look) and secondary (take-back). Primary cases detail the initial surgical interventions performed to stabilise the patient in the context of Damage Control Surgery (DCS), but also emergency DNBI cases such as caesarean, testicular torsion and ruptured ulcers. Secondary cases highlight surgical cases carried out thereafter i.e. take-back surgical cases on the same casualty, and included surgical procedures e.g. to remove or change dressings, or to refashion stumps etc.

Each surgical case was assigned to a specific body region (see itemisation of data subsection of methodology Chapter 3 e.g. AC abdominal cavity).

Each surgical case which required proximal vascular control was recorded in a separate column on the spreadsheet [Yes (Y); No (N)].

The data set was evaluated by demographics; case fatality rate and surgical procedures.

<u>Classification of surgical procedures</u>

Surgical procedures were calculated by the frequency performed as a percentage of total surgical procedures in the study (n=20,266) and enabled comparison between previous studies (e.g. Ramasamy et al., 2010; Jacobs et al., 2012). To assess the impact of surgical procedures on overall workload we also calculated the frequency each was performed as a percentage of overall case number, where applicable (n=10,891).

The surgical procedures were categorised following the classification of procedures from previous similar studies (Ramasamy et al., 2010; Jacobs et al., 2012), and adapted accordingly to enable comparison of percentages of total surgical procedures (n=20,266) (e.g. see Table 1). Using the index surgical procedures column of the database, along with the anatomical regions column, we were able to systematically analyse the database for each index surgical procedure (see Table 1).

To enable cross-comparison to previous periods of the conflict, for this study, each surgical procedure such as “debridement”, was recorded as a single procedure despite, in some cases, it being carried out on multiple wounds in the same case (operation). This is consistent with previous studies (Ramasamy et al., 2010; Jacobs et al., 2012), and allowed for comparison of data.

Damage Control Surgery (DCS) typically includes vascular procedures to stop bleeding such as proximal vascular control procedures. Vascular procedures that were not Damage Control (DC) included grafts, and shunts. We analysed operations/cases that involved proximal vascular control procedures separately.

The intent for Damage Control (DC) was not overtly documented. Analysis for primary blast cases that required Abdominal Cavity (AC) surgery and proximal vascular control were classified as Damage Control Surgery (DCS) laparotomies (DC laparotomy). Therefore, to identify cases which involved Damage Control Surgery (DCS) laparotomies, we carried out analysis of the database using the following search criteria: Primary; BLAST; required Proximal Vascular Control (PVC); and AC surgery.

The operation time was categorised into three groups (< or = to 90mins; >90mins; >300mins) (time in and out of theatre was documented in 10,880 cases). Percentage was calculated as a proportion of total cases (n=10,891). The three groups were selected in line with the accepted literature which supports 90 minutes as the appropriate cut-off time for stopping bleeding in damage control surgery (Hirshberg 1999; Waibel and Rotondo, 2010). I included an additional group of long cases that lasted >300 minutes (5 hours) for further analysis.

Patient demographics

The origin of the casualties was determined by nationality and were grouped into populations. Combatant population (n=5641): ANSF (Afghan National Army; Afghan National Police); Enemy Forces (EF) and ISAF (International Security Assistance Force) vs. Humanitarian (n=2747): Civilians (CIV - females, elderly, contractors); paediatric (PAEDS <16 years of age); and interpreters. We calculated the provision of primary and secondary surgical interventions for each demographic group as a percentage of cases where nationality was documented (n=8388). The database therefore includes all BI; DNBI; and procedures performed on civilians (Humanitarian-related operations). Each case was categorised as primary or secondary (incl. all subsequent surgical cases on the same casualty). Subsequently, we compared the demographic proportion of cases, to the previous study by Ramasamy et al., (2010) for comparison (Table 3). For this part of the analysis we did not differentiate between primary and secondary cases and the proportion is of operations where nationality was documented (n=8388) (Table 3).

Mechanism of Injury

Mechanism of injury analysis was performed by selecting only the primary surgical cases (n=5632) and calculating the percentage of each mechanism of wounding for each (Fig.1).

Statistical analysis

Statistical analyses were performed with the use of Excel Microsoft software, version 2016. To aid comparison to previous studies and for the present study, the methodology was kept as similar as possible to previous studies. Statistical analysis with z-test (z-value) was used to compare population proportions between our results and previous studies (Ramasamy et al., 2010; Jacobs et al., 2012). Because of the large dataset, the percentages are given to 1 decimal place to avoid rounding errors. Standard descriptive statistics were used to estimate the means of the study variables. Differences in baseline characteristics and clinical outcomes between study groups were assessed with the independent-samples Student's t-test for continuous variables. Statistical significance was accepted at the 5% level ($p<0.05$).

Results

During the study period 20,266 surgical procedures were carried out, or 1.86 procedures per case (Table 1).

Primary surgical cases accounted for 51.7% of total surgical cases (Table 2: n=5632 of 10,891).

Secondary surgical cases (take-back operations) accounted for 48.2% of cases (Table 2: n=5259 of 10,891).

Surgical case fatality rate (Died of Wounds DOW) was: 96 per 10,891 surgical cases (Table 2). Of those who DOW, 51.1% suffered a blast injury (Table 2: n=49 of 96). When, Disease Non-Battle Injury (DNBI) was excluded (appendectomy, n=1), 51.6% of total primary BI casualties that DOW suffered a blast injury (Table 2: n=49 of 95).

The proportion of primary operations (emergency) where the casualty DOW was 1.7% (Table 2: n=96 of 5632). The DOW rate was calculated as the proportion of total cases [Table 2: n=96 of 10,891(0.9%)].

Significantly more ISAF [Table 3: n=3121 of 8388 (37%)] and ANSF incl. EF [Table 3: n=2520 of 8388 (30%)] casualties received surgical care in our study than previous periods of the conflict (Ramasamy et al., 2010) (Table 3: ISAF: 37% vs. 32%; z=-3.881; p<0.0001; ANSF & EF: 30% vs. 27%; z=-2.454; p<0.001). The present study had significantly fewer civilian [Table 3: CIV: n=2165 of 8388 (25.8%)] and fewer paediatric casualties [Table 3: PAED: n=511 of 8388 (6.1%)] that received surgical care compared to previous periods of the conflict (Ramasamy et al., 2010) (Table 3: CIV:25.8% vs. 39%; z=10.967; p<0.001; PAED: 6.1% vs. 14.7%; z=12.159; p<0.001). Lastly, 0.8% of surgical cases were on interpreters (Table 3: n=71 of 10,891), not previously recorded in previous analyses (Table 3).

In total 32.7% of surgery was humanitarian (Civilian, paediatrics and interpreters) (Table 3: n=2747 of 8388).

The paediatric (PAED) patient average case age was 8 years (x = 8 ± 3.858 SD; n=60; range: 3months-15 years).

The average surgical cases per day were 6 (10,891 cases over a period of 1782 days) and 51.3% of total cases (n=5587 of 10,891) were carried out overnight (1800-0800 hours local time), significantly more than reported by previous studies (Ramasamy et al., 2010; Jacobs et al., 2012) (Table 2: 51.3% vs. 28%; z=-17.735; p<0.001).

The number of operations >90 minutes accounted for 43.9% of cases (n=4776 of 10,891).

The number of operations >300 minutes accounted for 2.8% of cases (n= 303 of 10,891).

The number of operations <90 or, equal to 90mins accounted for 56.0% (n = 6104 of 10,891).

Operations ≥300 minutes were further examined. We show that 76.2% of cases >300mins were primary operations on casualties that suffered blast and GSW injuries (n=231 of 303), and that 2 casualties in this group DOW (2.1%: n=2 of 95).

Proximal vascular control procedures were required in 24.1% of cases lasting more than 300 minutes (n=73 of 303). Abdominal Cavity (AC) surgery to gain proximal vascular control was used in 14.2% of cases with operation lengths more than 300 minutes (n=43 of 303), one of whom DOW.

The average duration of case was compared to the previous study (Ramasamy et al., 2010) and an increase was found (65 vs. 80 mins; t-value -166.72; p<0.001).

Of primary cases, Battle injuries (BI) accounted for 85.6% [total BI cases n=4821 of 5632 (Fig.1: BURN n=102; BLAST n=3136; GSW n=1576; Stabbing n=7)] and Emergency Disease Non-Battle Injury (DNBI) accounted for 14.4% of primary surgery (total primary DNBI cases n= 811 of 5632 [(NBI n=791, BITES n= 11, RTAs n= 9)] (Table 2; Fig.1).

The present study found that a high proportion of operations were on DNBI which accounted for 7.4% of total operations (Table 2: 811 of 10,891). The surgical burden of DNBI as a proportion of primary surgery was high, 14.4% of overall primary surgery workload (Table 2: n=811 of 5632).

We show a significant increase in DNBI surgical workload (7.4%) compared to previous years of the conflict (Ramasamy et al., 2010) (Table 2: 7.4% vs. 4%; z=-5.085; p<0.001). Since some cases were secondary DNBI operations, the total DNBI surgical case number was 825, or 7.6% of total surgical cases (n=825 of 10,891). There were 335 appendectomy procedures, one of whom died (Table 2).

In the present study, the most common primary DNBI procedure in war-time was appendectomy which was performed in 41.3% of primary DNBI cases (Table 2: appendectomy n=335 of 811). Previous studies reported abscess-related procedures to be the most common DNBI procedure (Ramasamy et al., 2010; Jacobs et al., 2012).

Casualties that suffered blasts or explosions, Battle Injury (BI), accounted for 55.7% of primary surgery (Fig. 1: n=3136 of 5632). Our study presents a significant decrease in BI primary surgery [Table 2: n=4821 of 10,891 (44.3%)] compared to previous years of the conflict (Ramasamy et al., 2010) (Table 2: 44.3% vs. 47.7%; z=2.370; p<0.05).

A breakdown of the most commonly performed procedures is shown in Table 1 (not including DNBI): The top 10 most frequently performed surgical procedures as a percentage of total procedures (n=20,266), were: wound debridement (15.8%); Negative Pressure Wound Therapy (NPWT) (10.7%); amputations (8.5%); laparotomies (8.0%); Delayed Primary Closure (DPC) (6.3%); head and neck surgery (6.2%); hand surgery (6.1%); application of external fixator (5.2%); vascular procedures (4.9%); fasciotomy (2.5%); and eye procedures (2%) (Table 1).

Laparotomy procedure was performed in 14.9% of operations (Table 1 n=1624 of 10,891) and accounted for 8.0% of total surgical procedures (Table 1: n=1624 of 20,266). This is significantly increased from previous analyses (Ramasamy et al., 2010) (Table 1: 8.0% vs. 4.8%; z=-5.363; p<0.0001) and significantly decreased from previous studies (Jacobs et al., 2012) (Table 1: 8.0% vs. 9.1%; z=2.675; p<0.001).

Just 22.9% of surgical cases involving a laparotomy procedure had operative times under 90 minutes (n=372 of 1624), the recommended upper time-limit for Damage Control Surgery (DCS) laparotomy. Damage Control (DC) laparotomies were carried out in less than 90 minutes 7.2% of the time (Fig.2: 11 of 153) and 54.5% DOW (Fig.2: n=6 of 11). Compared to 92.8% of DC laparotomy operations lasting greater than 90 minutes (Fig.2: n=142 of 153) and 4.9% DOW (Fig.2: n=7 of 142).

Amputation procedure occurred in 8.5% of total surgical procedures (Table 1: n=1723 of 20,266). The present study shows that significantly more amputation procedures were carried out compared to previous years of the conflict (Ramasamy et al., 2010) (Table 1: 8.5% vs. 3.8%; z=-7.717; p<0.001) and there was no significant difference when compared to Jacobs et al., (2012) (Table 1: 8.5% vs. 8.4%; z=-0.240; p>0.05).

The present study finds significantly fewer amputations were carried out Above Knee (AKA) [Table 1: n=334 of 1723 (19.4%)] compared to previous years of the conflict (Jacobs et al., 2012) (Table 1: 19.4% vs. 48%; z=12.718; p<0.001).

Bilateral amputations accounted for 28.5% of amputation procedures (Table 1: n=492 of 1723), not previously recorded, and 57% of amputations were primary (n=982 of 1723). Amputations were performed in 15.8% of all surgical cases (n=1723 of 10,891).

There were 990 vascular procedures including proximal artery/vein repair and/or grafting and Temporary Vascular Shunting (TVS). Vascular procedures were required in 9.1% of cases (Table 1: n=990 of 10,891). We show a significant increase in vascular procedural workload, and that vascular procedures took place in 4.9% of operations (n=990 of 20,266) or a four-fold increase compared to previous analyses (Ramasamy et al., 2010) (Table 1: 4.9% vs. 1.1%; z=-8.160; p<0.001). Vascular procedures to gain proximal vascular control, a Damage Control (DC) procedure, were required in 3.3% of cases (n=360 of 10,891).

Of the cases that required proximal vascular control (n=360), 23% (n=82 of 360) were on Above Knee Amputations, and 25% were cases involving bilateral amputations (n=90 of 360).

Surgical application of Negative Pressure Wound Therapy (NPWT) for complex wound management accounted for 10.7% of surgical procedures (Table 1: n=2167 of 20,226), not previously recorded.

In addition to the above, we found surgical procedures to the eye were carried out in 3.8% of surgical cases (operations) (Table 1: n=414 of 10,891), and 2% of surgical procedures carried out were eye related which is a significant increase to Jacobs et al., (2012) (Table 1: 2% vs. <1%; z=-5.058; p<0.001).

The application of an external fixator was found to be used in 9.7% of operations (n=1051 of 10,891) or 5.2% of surgical procedures (n=1051 of 20,266) (Ramasamy et al., 2010; Jacobs et al., 2012) (Table 1: 5.2% vs. 2.9%; z=-4.723; p<0.001; 5.2% vs. 4.5%; z=-2.138; p<0.05).

We found the following surgical procedural workload in the present study, remained similar, or statistically insignificant, to Ramasamy et al., (2010): hand 6.1% (Table 1: 6.1% vs. 6.4%; z=0.558; p>0.05); head and neck 6.2% (Table 1: 6.2% vs. 6.3%; z=0.185; p>0.05); fasciotomy 2.5% (Table 1: 2.5% vs. 2.1%; z=-1.153; p>0.05); and thoracotomies 1.1% (Table 1: 1.1% vs. 1.4%; z=1.267; p>0.05).

There was a significant reduction in the following procedures compared to previous analyses (Ramasamy et al., 2010; Jacobs et al., 2012) (Table 1):

- Skeletal traction pins (0.5%)
  (Table 1: 0.5% vs. 1.1%; z=3.592; $p<0.001$ and 0.5% vs. 1.3%; z=6.526; $p<0.001$)
- Neurosurgery (0.1%)
  (Table 1: 0.1% vs. 1.8%; z=14.702; $p<0.001$)
- Debridement 15.8%
  (Table 1: 15.8% vs. 34%; z=21.339; $p<0.001$ and 15.8% vs. 43.9%; z=45.359; $p<0.001$)
- Burn related procedures (1.1%)
  (Table 1: 1.1% vs. 4.7%; z=13.425; $p<0.001$ and 1.1% vs. 1.5%; z=2.468; $p<0.05$)
- Delayed Primary Closure (DPC) procedures (6.3%)
  (Table 1: 6.3% vs. 17.8%; z=-40.958; $p<0.001$ and 6.3% vs. 10.1%; z= -70.771; $p<0.001$)
- Split- Thickness Skin Graft (SSG) 1.1%
  (Table 1: 1.1% vs. 2.1%; z= 4.103; $p<0.001$)

Total skin graft procedures (incl. full thickness etc.) accounted for 1.4% of the total surgical procedures (Table 1: n=334 of 20,266).

Comparison of the present study findings to Jacobs et al., (2012) found the following significant decreases in Fasciotomy procedural workload [Table 1: n=497 of 20,266 (2.5%)] (Table 1: 2.5% vs. 3.1%; z=2.506; 0.012) and thoracotomy procedures [Table 1: n=222 of 20,266 (1.1%)] (Table 1: 1.1% vs. 1.7%; z=3.637; $p<0.001$) and no significant difference in SSG [Table 1: n=257 of 20,266 (1.1%)] (Table 1: 1.1% vs. 1.3%; z=1.257; $p>0.05$).

Discussion

Since 2006, MI5 and the Home Office have put the National Threat level from international terrorism at critical, severe, or substantial and since 2015, the National Threat Level has been at Critical or Severe, the two highest levels ("Threat-levels", 2018). Given the rise in terror attacks in 2017, a step change is required in the training of surgeons to meet the surgical needs of terror attacks and Mass Casualty Events (Moran et al., 2017; Smith et al., 2017).

How we achieve this remains unclear. Courses go some way, but uptake is low. For example, a third of general surgical consultants on-call at Major Trauma Centres (MTCs) have not completed either the Definitive Surgical Trauma Care (DSTC) or Definitive Surgical Trauma Skills (DSTS) courses available to gain these additional trauma skills (Smith et al., 2017). In the UK we do not see sufficient trauma to gain the experience required, and so the reliance on civilian trauma exposure is not a sufficient solution (Moran et al., 2017).

Ramasamy et al., (2010) analysed 1668 surgical cases (2210 procedures) from a 2-year period of the Afghanistan conflict and classified surgical procedures by specialty, and from this suggested the recommended surgical team skill set to be a combination of orthopaedic, vascular, thoracic, and neurosurgical procedures (Parker, 2008; Ramasamy et al., 2010; Jacobs et al., 2012). Schwab (2015) wrote that the American surgical experience was similar to Ramasamy et al., (2010). We systematically highlight significant differences to the classification of surgical procedures previously proposed (Ramasamy et al., 2010).

The initial analysis of the database, 10,891 cases gave rise to 20,266 surgical procedures or 1.83 procedures per case. The workload from the end of 2009-Sept 2014 was higher than reported previously (Ramasamy et al., 2010 and Jacobs 2012). We show that 51.3% of all cases occurred overnight outside of daylight hours (1800-0800), significantly increased compared to Ramasamy et al., (2010).

Surgical case fatality rate (Died of Wounds DOW) was 0.9% (Table 2: 96 of 10,891) and 51.1% of those who DOW suffered from blast injuries (Table 2: n=49 of 96). The 0.9% DOW rate we have reported here is a significant decrease in the case fatality rate of 2.36% DOW found by Nessen et al., (2009) in the beginning half of the conflict in Afghanistan. The reasons for this remain unclear, and we aim to analyse this finding further in future chapters.

The principles of Damage Control (DC) Surgery (DCS) and Damage Control Resuscitation (DCR) are well established and appreciated (Bilski et al., 2003; Blackbourne et al., 2011;

Waibel and Rotondo, 2012). Thus, primary DC laparotomies to control haemorrhage, should ideally be performed in less than 90 minutes (Hirshberg 1999; Waibel and Rotondo, 2010). In the present study just 23% of DCS laparotomies reached this cut off. We analysed this further and identified DC laparotomy cases that had "quick-fixes" e.g. for haemostasis and contamination control and found that 7.2% were <90mins (n=11 of 153) (Fig.2). Laparotomy procedures significantly increased compared to Ramasamy et al., (2010) but were down significantly compared to Jacobs et al., (2012) at 8.0% of total procedures (Table 1). Future analysis of the present data set will examine what procedures were carried out during laparotomies within the Abdominal Cavity (AC) and whether surgical experience had any impact on outcomes such as duration of operation and case fatality (see Chapter 6 and Chapter 7).

In the present study, the average duration of surgery increased significantly to 80 mins compared to the 65 mins previously reported (Ramasamy et al., 2010). The poly-trauma patient associated with blast injuries e.g. from Improvised Explosive Devices (IEDs), is perhaps the reason why 2.8% of operations lasted longer than 300 minutes. However, 56% of operations were within the 90-minute threshold for DCS. We analysed the cases that required over 300 minutes of operative time further and found that, 76.2% were for primary, Blast/GSW trauma (n=231 of 303) and 2% of these operations (cases) DOW, (n=2; primary BI DOW n=95). It is a concern that 76.2% of these lengthy operations (>300minutes) were performed on emergency trauma casualties. This perhaps reflects the multiplicity of wounding typified by the conflict in Afghanistan, but also suggests that a variation in approach to Damage Control Surgery when tackling poly-trauma injuries associated with blasts/explosions, may be evident. In order to understand this further, we analysed the cohort of cases greater than 300 minutes in duration in more detail as follows.

A significant cause of preventable death is bleeding in non-compressible regions of the body e.g. axilla, groin, and neck (Schwab 2015). In such instances, proximal vascular control procedures are required (e.g. abdominal cavity, or chest cavity surgery) for haemorrhage control. We report, for the first time, that proximal vascular control procedures occurred in 360 cases. Of these 360 cases, up to a quarter were to gain control for above knee amputations [(n=82 of 360 (23%)] and a quarter were to gain control of bilateral amputations [(n=90 of 360 (25%)].

To gain proximal vascular control is a Damage Control (DC) procedure and it is perhaps, therefore, a concern that 24.1% of primary operations that lasted >300 minutes, underwent proximal vascular control (n=73 of 303). This falls well outside of the recommended DCS timeframe. In addition, to gain proximal vascular control, the abdominal cavity is sometimes opened (Damage Control laparotomy) and 14.2% of operations >300 minutes required Abdominal Cavity (AC) surgery to gain proximal vascular control (n=43 of 303), one of whom DOW. We show again, that the principles of DCS are not always being followed; further analysis is required to assess the effect, if any, on surgical outcomes.

The finding that almost a quarter of trauma casualties underwent initial surgery lasting over 300 minutes also received Damage Control procedures and that 76.2% of cases over 300 minutes were primary operations on casualties that suffered blast and GSW injuries [(n=231 of 303 (76.2%)] and that 2 casualties within this group went on to Die of Wounds (DOW) (2.1%: n=2 of 95) highlights that there may be a lack in standardisation of the approach to trauma surgery.

Orthopaedic procedures like amputation were significantly increased (Table 1) when compared to previous analyses (Ramasamy et al., 2010), but were similar to the 8.4% of total procedures reported by Jacobs et al., (2012), suggesting that in future conflicts a figure around 8% of procedural workload could to be expected. The finding, for the first time that 28.5% of amputations were bilateral has implications for future planning and surgical provision; for example, that troops/civilians have readily available at least two functioning tourniquets, and that surgical teams are prepared to receive bilateral amputees in about a third of cases.

A key principle of pre-hospital care emphasises the preservation of eyesight (Battlefield Advanced Trauma Life Support BATLS). The present study finds that the surgical burden of eye injury was significantly increased compared to previous periods of the conflict, and despite the introduction of ballistic eye protection in 2006. Further development continues in this area of Personal Protective Equipment (Ramasamy et al., 2010; Breeze et al., 2011; Jacobs et al., 2012) (Table 1).

For the first time we describe the surgical workload of secondary cases. This amounted to 48.3% of total cases over the 5-year study period (Table 2). Initial analyses show that wound management techniques e.g. NPWT accounted for 10.7% of total surgical procedures (Table 1). We anticipate that the burden of definitive and secondary surgical care may increase in future conflicts as it may not always be possible to set up an equivalent field-based hospital facility typified by Camp Bastion. As a result, surgeons may be further forward, with less provision, and may have to carry out more definitive surgery as patients endure prolonged extraction times. Further analysis to establish the most frequently performed surgical procedures, primary and secondary, from our most recent armed conflict, will aid planning for the next.

After the explosion of an IED, those in the vicinity (civilians, children, contractors) with severe battle-injuries (BI) may require essential operations that prepare them to return to their local environment where adequate healthcare, long-term rehabilitation, or follow-up care may be poor or may not exist. Our initial analysis of the present dataset shows that a high proportion of surgery carried out (32.7%) was humanitarian (civilian, paediatrics and interpreters) although this is a significant decrease to Ramasamy et al., (2010) (Table 3). It is currently unknown how the operations carried out on local populations affected by conflict contributes to, or changes, the surgical skill set requirement for the war surgeon (Charnley, 2003; Ramasamy et al., 2010). We aim to analyse this in Chapter 5 to establish the skill-set for humanitarian casualties caught up in war.

Disease-Non-Battle-Injury (DNBI) accounted for 14.4% of primary surgery or 4.1% of total procedural workload, a significant increase compared to the 2.8% reported by Jacobs et al., (2012) (Table 1). The present study shows that the DNBI procedure most commonly performed was appendectomy, as opposed to Incision and Drainage (I&D) of abscesses previously recorded (Jacobs et al., 2012). The surgical procedures required for DNBI in the conflict environment is not yet fully analysed and since it is unlikely to change in the future, we suggest that DNBI surgery will be a significant part of the skill set requirement for combat surgeons in the future and we aim to develop a DNBI template for surgical procedures in conflict in our next study (Chapter 5).

A number of surgical procedures are carried out less frequently compared to the previous classification of procedures in Afghanistan (Ramasamy et al., 2010) (see Table 1). As a result of the changes outlined in the present study, we suggest that the surgical skill set be adjusted accordingly. The findings of the present study support Schwab (2015), that the definitive surgical skill set for war does not presently exist, and that this has implications for future conflicts and provision of surgery for terror attacks (Smith et al., 2017).

The future of trauma surgical care is likely to be a broad base of surgical competencies. No one individual or organisation is currently accountable for the readiness of surgical provision in future combat operations. We hope that by analysing the present study's large, contemporaneous and consecutive database, we provide an insight into the surgical activity performed during the conflict so that we can aim to alleviate the "slipping back" in surgical readiness that inevitably occurs between conflicts during peacetime.

Limitations

Limitations of this study are due to its retrospective nature and its reliance on correct recording in the original manuscript e.g. the nationality of cases was not recorded consistently. However, there is minimal selection bias as such (Eastridge, 2010) because all cases operated on were recorded into the theatre log-book regardless of injury.

Further work

The present study shows a variation in approach to Damage Control Surgery which suggests that standardisation in trauma surgery is yet to be agreed.

Chapter 4 highlights key differences to previous classifications of surgical workload in war by Ramasamy et al., (2010). The suggested surgical team skill set for conflict that exists today needs to be adapted accordingly, and as a result of the findings of the present study. Further work is needed (Schwab, 2015).

Chapter 5 will focus on humanitarian surgery carried out to manage civilian casualties. In addition, we aim to develop a template for surgical procedures required for DNBI in future conflicts, given the high proportion of DNBI surgery shown in the present study.

This study forms part of a large piece of work that is needed to improve the standardisation of trauma surgical care in conflict zones across all three US services and NATO partners which does not currently exist (Schwab, 2015).

Conclusion

The present study highlights key significant differences from past classifications of surgical procedures in Afghanistan. Previous studies proposed the surgical skill-set required for war from small data-sets (n=1668 and n=4276 cases respectively (Ramasamy et al., 2010; Jacobs et al., 2012), however, the present study (10,891 cases) highlights key statistically significant differences to these previous classifications of surgical procedures. We show that the comprehensive surgical skill set for war is yet to be determined.

Figures and Tables

Figure 1 Mechanism of Wounding

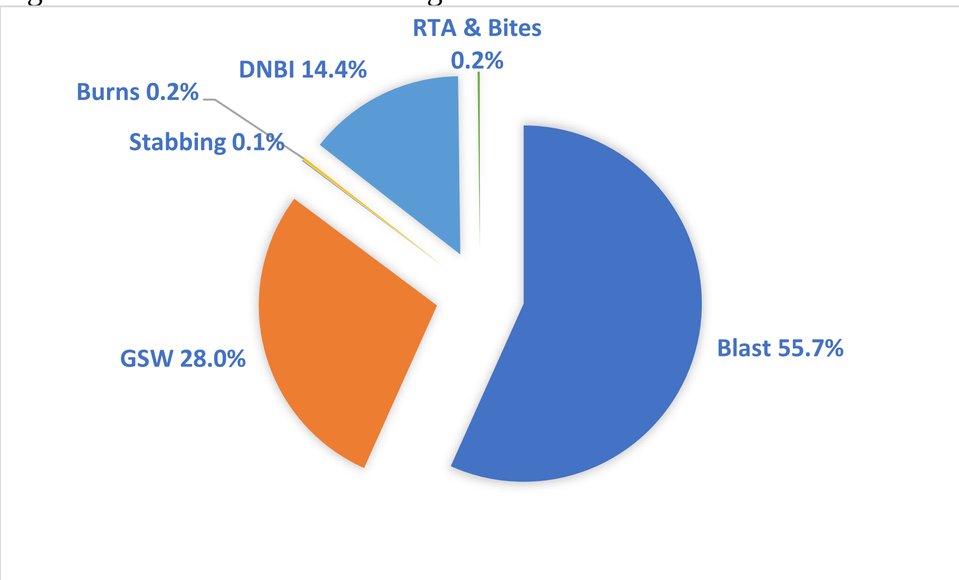


Fig.1 Proportion of total primary cases (n=5632) per mechanism of wounding. Of primary cases, Battle injuries (BI) accounted for 85.6% [total BI cases n=4821 of 5632 (BURN n=102; BLAST n=3136; GSW n=1576; Stabbing n=7)] and Emergency Disease Non-Battle Injury (DNBI) accounted for 14.4% of primary surgery (total primary DNBI cases n= 811 of 5632 [(NBI n=791, BITES n= 11, RTAs n= 9)].

Figure 2. Damage Control (DC) Laparotomy

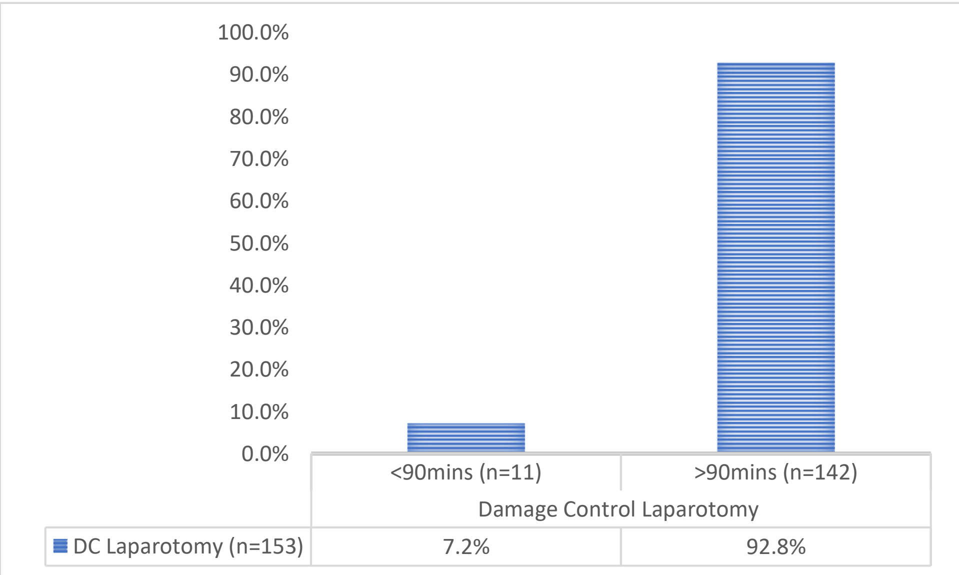


Fig.2 Proportion of Damage Control (DC) laparotomies (n=153) carried out <90mins and >90mins. [<90mins 7.2% (n=11 of 153) and 54.5% DOW (n=6 of 11). Compared to 92.8% of DC laparotomies >90mins (n=142 of 153) and 4.9% DOW (n=7 of 142)].

Table 1: Surgical requirements for war

The Classification of Surgical Procedures in Afghanistan					
	A Ramasamy et al., (2010)	B Jacobs et al., (2012)	C Present study (2009-2014)	z-value	p-value
Years	May 2006-May 2008	Nov 2008- Nov 2010	Nov 2009- Sept 2014		
Total surgical cases	1668	4276	10,891		
Total Procedures	2210	5737	20,266 or 1.86 procedures per case		
Percentages of total procedures per study					
Debridement	751* 34.0%	2516 43.9%	3201 15.8%	A vs. C 21.339 B vs. C 45.359	 0.000 0.000
Laparotomy	106 4.8%	524 9.1%	1624 8.0%	A vs. C -5.363 B vs. C 2.675	 0.000 0.008
Thoracotomy	31 1.4%	100 1.7%	222 1.1%	A vs. C 1.267 B vs. C 3.637	 0.205 0.000
Vascular Procedures	25 1.1%	Not recorded	990 4.9%	A vs. C -8.160	 0.000
Application of External-Fixator	63 2.9%	260 4.5%	1051 5.2%	A vs. C -4.723 B vs. C -2.138	 0.000 0.033
Amputations	85 3.8%	483 8.4%	1723 8.5%	A vs. C -7.717 B:C -0.240	 0.000 0.810
- Bilateral	Not recorded	Not recorded	492 28.5%		
- Above Knee Amputation (AKA)	Not recorded	48% of all amputations	334 19.4%	B vs. C 12.718	0.000
Skeletal traction pins	24 1.1%	72 1.3%	108 0.5%	A vs. C 3.592 B vs. C 6.526	 0.000 0.000
Fasciotomy	46 2.1%	178 3.1%	497 2.5%	A vs. C -1.153 B vs. C 2.506	 0.249 0.012
Manipulation under anaesthesia (MUA)	56 2.5%	119*** 2.1%	105 0.5%	A vs. C 10.734 B vs. C 11.634	 0.000 0.000

	A Ramasamy et al., (2010)	B Jacobs et al., (2012)	C Present study (2009-2014)	z-value	p-value
Hand surgery	142 6.4%	Not recorded	1227 6.1%	A vs. C 0.558	0.577
Head and Neck Surgery	139 6.3%	Not recorded	1253 6.2%	A vs. C 0.185	0.853
Eye surgery	Not recorded	<1%	414 2%	B vs. C -5.058	0.000
Neurosurgery	39 1.8%	Not recorded	25 0.1%	A vs. C 14.702	0.000
Burns Procedures	104 4.7%	88 1.5%	227 1.1%	A vs. C 13.425 B vs. C 2.468	0.000 0.014
Split Thickness Skin Graft (SSG)	46 2.1%	77 1.3%	257 1.1%	A vs. C 4.103 B vs. C 1.257	0.000 0.209
Total skin graft procedures	Not recorded	Not recorded	334 1.6%		
Delayed Primary Closure	394 17.8%	577 10.1%	1269 6.3%	A vs. C -40.958 B vs. C -70.771	0.000 0.000
Negative Pressure Wound Treatment	Not recorded	Not recorded	2167 10.7%		

*Ramasamy et al., 2010 had debridement torso and abdomen (n=144; n=607 respectively). **total Incision and Drainage of abscesses (no- DNBI figure). *** included Plaster of Paris POP procedures

Table 1: Proportions of total surgical procedures that were performed in the present study column C and previous studies; column A: Ramasamy et al., (2010); column B: Jacobs et al., (2012); according to the adaptation of the classification of surgical procedures (Ramasamy et al., 2010).

Table 2 Classification of Case

Classification of Case (Operation)					
	A Ramasamy et al., (2010)	B Jacobs et al., (2012)	C Present study	z-value	p-value
Total surgical cases	1668	4276	10,891		
Primary cases	Not recorded	Not recorded	5632 51.7%		
Primary Battle injury (BI)	796 47.7%	Not recorded	- 4821 44.3%	A vs. C 2.370	0.018
Disease Non-Battle Injury (DNBI)	67 4%	Not recorded	811* 7.4%	A vs. C -5.085	0.000
Secondary cases	Not recorded	Not recorded	5259 48.3%		
Cases performed between 1800-0800	28.0%	Not recorded	5587 51.3%	A vs. C -17.735	0.000
DOW - DNBI - Blast	Not recorded	Not recorded	96 [96 of 10,891, (0.9%)] 1[×] 49 51.1% (49 of 96)		

*appendectomy procedure n=335, one of whom DOW [×]

Table 2: Proportions of total surgical cases that were primary; secondary; BI and DNBI in the present study column C, and previous studies column A: Ramasamy et al., (2010); column B: Jacobs et al., (2012); according to the adaptation of the classification of surgical procedures (Ramasamy et al., 2010). The present study (C) shows the proportion of operations performed between 1800-0800 (local time). The proportion of casualties that DOW (n=96) and suffered blast, or DNBI, who DOW is shown.

Table 3 Casualty Nationality

Total	Nationality	A Ramasamy et al., (2010)	C Present study	A vs. C z-value	p-value
Combatants N=5641	ISAF	32%	3121 37%	-3.881	0.000*
	ANSF	See below ANSF +EF	1798 21.4%		
	EF ANSF + EF	27%	722 8.6% 2520 30%	-2.454	0.014*
Humanitarian N = 2747	PAED	14.7%	511 6.1%	12.159	0.000*
	Interpreter	Not recorded	71 0.8%		
	CIV	39%*	2165 25.8%	10.967	0.000*

[*(p<0.05)]

Table 3: Proportion of surgical cases documenting origin of casualty (nationality: n=8388) in the present study (column C) compared to Ramasamy et al., 2010 (n=1668) (column A). The present study determined the origin of the casualties by nationality and were grouped into the following populations: Combatants (n=5641): ANSF (Afghan National Army; Afghan National Police); Enemy Forces (EF) and ISAF (International Security Assistance Force) vs. Humanitarian (n=2747): Civilians (CIV - females, elderly, contractors); paediatric (PAEDS <16 years of age); and interpreters.

Chapter 5

Humanitarian surgery in conflict: Afghanistan, 2009-2014

II -The Disease Non-Battle Injury (DNBI) and Humanitarian Surgical skill set

Abstract

Background:

Future conflicts are likely to have prolonged evacuation times, austere environments and potentially less availability of medical resources compared to the recent conflict in Afghanistan, while the requirement for DNBI and humanitarian surgery is likely to remain (The Telegraph, 2012; Military blood, 2017). We analyse the surgical activity performed when different types of casualties are being treated (i.e. was the requirement for definitive secondary surgery greater when International Security Assistance Force (ISAF) casualties predominated, or when civilians were treated?). Casualty nationality data were used as a proxy to examine any difference in the surgical activity for a population that was wearing protective body armour (ISAF) and those who did not wear body armour (civilians). This would have implications for future team planning and surgical training depending on the type of casualties expected in future conflicts.

Methods:

Data was gathered from the Role 3 Medical Treatment Facility, Camp Bastion, Afghanistan, 2009-2014, the end of UK formal operations in Afghanistan- 10,891 surgical cases and 20,266 surgical procedures were analysed. The origin of the casualties was determined by casualty nationality (n=8388). Disease Non-Battle Injury (DNBI) cases (n=825) were identified and analysed. The combat activity, wounding patterns, surgeons and mission emphasis of the hospital, changed throughout the years of the conflict studied. Statistical analysis with z-test were used to compare proportions of injuries, nationalities and surgical procedures carried out. Statistical significance was accepted at the 5% level ($p<0.05$).

Results:

The analysis of case fatality rates showed that civilian casualties were more likely to die in armed conflict (1.5%) than were combatants (0.8%) (1.5% vs. 0.8%; $z=-3.657$; $p<0.001$).

Significantly more definitive, secondary surgery (57.3%) was carried out on civilian casualties, compared to primary (42.7%) (57.3% vs. 42.7%; z=-10.377; p<0.001). Civilian casualties suffered significantly more torso (16.1%) and abdominal cavity trauma (24.5%) compared to ISAF, wearing body armour (16.1% vs. 7.9%; z=-6.812; p<0.001) (24.5% vs. 12.6%; z-8.191; p<0.001). Combatants accounted for 74.7% of DNBI surgery and 1 in 6.9 cases were DNBI. The most common DNBI procedure was appendectomy, 3.1% of all cases (n=335 of 10,891), compared to Jacobs et al., (2012), 2.5% (3.1% vs. 2.5%; z=1.971; p<0.05). Of "Junctional Zones" the neck was the most commonly affected in combatants (ISAF) (4.3%) and adult civilian groups compared to groin (1.7%) and axilla (0.5%). Paediatric casualties had significantly fewer neck injuries (1.4%) than ISAF or civilian adults (1.4% vs. 4.3%; z=2.090; p<0.05 and 1.4% vs. 4.7%; z=2.239; p<0.05). Unilateral upper extremity trauma was more likely in ISAF (19.0%) and civilian casualties (15.0%) than bilateral upper extremity trauma (19.0% vs. 9.0%; z=9.204; p<0.001) (15.0% vs. 6.8%; z=5.741; p<0.001). The most common region of paediatric trauma was the face (31.1%). The most common region of civilian adult trauma was the abdominal cavity (24.5%). The most common region of ISAF trauma was bilateral lower extremity (27.1%).

Conclusions:

No matter where the next armed conflict is, there will be a requirement for the surgical provision of DNBI and civilian casualties. Here we suggest the surgical template for procedures to manage DNBI burden in conflict as well as the humanitarian skill set for the surgical treatment of local adult civilian population and children, and provide data to inform future planning for surgical provision in conflict zones.

Introduction

The focus of this study is to outline the Disease Non-Battle Injury (DNBI) surgery and humanitarian surgery most utilised in conflict through the analysis of the consecutive surgical cases performed in Afghanistan from 2009 to the official end of operations in Afghanistan 2014.

This study leads on from a brief initial sample analysis of the database presented in Maitland et al., (2016) (Chapter 1) and specifically aims to analyse the surgical management of Battle Injuries (BI) sustained by the local civilian adult (CIV), and paediatric (PAEDS) population. In addition, the study will analyse the surgical management of Disease and Non-Battle Injury (DNBI) in conflict.

In accordance with Geneva conventions, civilian casualties with severe battle-injuries (BI) were brought to the field hospital Camp Bastion, Afghanistan (Arul et al., 2012). This cohort included middle aged casualties (e.g. local contractors; interpreters) with potential co-morbid conditions and often malnourished states; each presenting a unique challenge to the combat surgeon. The surgery carried out on the local population affected by conflict and its impact on the combat surgeon has not yet been analysed. Nor, how this need may contribute to, or change, the surgical skill set requirement for the conflict surgeon (Charnley, 2003; Edwards et al., 2012, 2014; Ramasamy et al., 2010). Previous attempts have been made to outline the surgical impact of non-combatant casualties on surgical provision. Such studies, however, primarily focus on the description of injury patterns, mechanisms of injury, and numbers of casualties, as opposed to the surgical ramifications of these on surgical interventions. The present study aims to analyse the surgical cases of civilian casualties that suffered BI and DNBI injuries. This study aims to outline an initial analysis of the humanitarian surgery performed on this patient demographic.

Initial analysis of surgical cases involving plastic surgeons showed that they were involved in over 40% of cases and that casualty demographics changed during the study period, specifically that more ANSF cases appeared as the ISAF began to hand over command (Maitland et al., 2016). The surgery performed must prepare the casualty to return to their local environment where potentially no healthcare provision, nor long-term rehabilitation or follow-up care may exist. The reduced health care provision of the home nations leads to the hypothesis that a higher proportion of secondary operations or definitive surgical procedures more traditionally carried out after evacuation of ISAF to home nations, were accounted for by CIV, ANSF, Interpreters (INTERP), and PAEDS, at the Field Hospital in Afghanistan.

In Chapter 1 we showed that there were significantly less civilian cases than reported by previous studies and that combatant casualties increased compared to previous studies (Maitland et al., 2016). However, since 48.2% of the surgical caseload overall was secondary take-back, we aim here to find out if humanitarian casualties accounted for most of the secondary surgery since they were to return to the relatively poor health care system of the host-nation.

Ramasamy et al., (2010) reported that paediatric casualties accounted for 14.7% of 1668 surgical cases, a figure overall higher than in the Iraq conflict. Another study conducted in the Afghanistan conflict reported that paediatric trauma (blast, penetrating, blunt or burn) accounted for 5.8% of all admissions, and found that the mortality rate was higher in the paediatric group than in the adult civilian, or coalition forces (Borgman, 2012). We aim therefore, to use casualty nationality as a proxy to examine any difference in the body regions being operated on for a population that was wearing protective body armour (ISAF) and those who did not (civilians). This would have implications for future team planning for conflict, depending on the type of casualties expected. In addition, we analyse the surgical skill set used to return humanitarian casualties of conflict to their home nation's health care system in the remote austere environments of conflict zones. We analyse the surgical cases from 2009-2014 to outline the surgical procedures carried out on the local population swept up in conflict, so that we can inform surgical provision for future modern conflicts using the current study as a model.

To date, few studies have analysed the surgical caseload of DNBI in conflict, and although Belmont et al., (2010) reported high rates of evacuation for DNBI, the surgical burden was not documented in their study. Ramasamy et al., (2010) gave an overall percentage for DNBI of 4% of the cases analysed in their study. Since the present study is the largest contemporaneous surgical dataset to come from conflict, we hope to document the complete set of surgical procedures carried out in Afghanistan, and to ascertain the top 5 most commonly performed procedures so that we might develop a surgical template for DNBI management for future conflicts.

In addition to BI surgical cases, combat surgeons are also required to perform emergency DNBI operations like civilian trauma duties, such as burns, appendectomies and mangled extremities from car crashes etc. (Parker, 2000). There are few peer-reviewed studies on the DNBI surgical procedures performed on local populations (Local Nationals LN: civilian children, Afghan National Army - ANA and Afghan National Police – ANP, Afghan National Security Forces, ANSF) and allied troops (International Security Assistance Forces, ISAF).

Methods

Study design and patient identification

A retrospective analysis of operating theatre records between November 5, 2009, and September 21, 2014 was performed. The total surgical cases (n=10,891) performed in the latter half of the conflict in Afghanistan until 2014, the end of UK formal operations in Afghanistan at Role 3 Camp Bastion Facility were analysed. Because the combat activity, wounding patterns, surgeons and mission emphasis of the hospital, changed throughout the years of the conflict studied, cases were selected for analysis in the present study based on mechanism of injury (DNBI); nationality (civilians vs. combatants) and operation type (primary vs. secondary).

Mechanism of Injury

Individual surgical cases were categorised by mechanism of injury and classified as Battle Injury (BI): Gun Shot Wound (GSW); BURNS incl. Acid and Chemical attacks, BLAST or explosions incl. IED, Mortar, Grenade; Gun Shot Wound (GSW); and Stabbing; DNBI (Disease Non-Battle Injury) that incl. Road Traffic Accidents (RTAs) and Bites analysed: Disease Non-Battle cases.

Types of surgical activity

Surgical cases (operations) were analysed according to the operation type (primary (first-look); secondary (take-back)) surgery. Primary surgery details both the initial surgical interventions performed to stabilise the patient in the context of Damage Control Surgery (DCS), and the casualties that suffered emergency DNBI such as caesarean, testicular torsion and ruptured ulcers. Secondary surgery highlights surgical cases carried out thereafter i.e. take-back surgical cases on the same casualty and included further surgical procedures e.g. to remove, or change dressings, or to refashion stumps, etc.

To aid comparison to previous studies, and for the present study, methodology was kept as similar as possible e.g. each procedure was counted once per case, despite multiple body regions being operated on (e.g. debridement).

The surgical activity when different nationalities of casualties were undergoing surgery was analysed to see whether the requirement for primary vs. secondary surgery changed when civilians or ISAF were being treated.

Demographics and Nationality

Humanitarian surgery included civilian casualties: Paediatric (PAEDS); Civilian adult (CIV); and Interpreters (INTERP). Combatants included ISAF International Security Assistance Force; ANSF Afghan National Security Force; EF enemy forces.

Nationality was recorded in 8388 cases (total surgical cases: n=10,891) and percentages were calculated per demographic.

In addition, we analysed the surgical activity when different types of casualties were being treated (i.e. was the requirement for definitive secondary surgery greater when ISAF casualties made up most of the casualties, or when civilians were the bulk of the patients treated?).

These data were used as a proxy to examine any difference in the surgery performed on a population that was wearing protective body armour (ISAF) compared to one not wearing body armour (civilians). ANSF casualties were excluded from this analysis as they wore a varying degree of body armour which was not recorded. Primary cases were analysed and DNBI were excluded from this analysis.

Body regions of trauma surgery

Each primary case (operation) was categorised into body regions that suffered trauma and is consistent with previous studies as follows:

RLE right lower extremity

LLE left lower extremity

BLE bilateral lower extremities

Torso Wall TW (back, flank, chest wall)

Buttock (buttocks)

Perineum (anorectal region, scrotum, male and female genitalia)

AC Abdominal Cavity

CC Chest Cavity

Head

Neck

Face

Hand

LUE Left Upper Extremity

RUE Right Upper Extremity

BUE Bilateral Upper Extremity

Statistical analysis

Statistical analyses were performed using Excel Microsoft software, version 2016. Statistical analysis with the z-test was used to compare population proportions of body regions, types of surgery, nationalities and mechanisms of injury. Statistical significance was accepted at the 5% level $p<0.05$).

Results

The database was analysed and of the 10,891 surgical cases, casualty nationality was recorded in 8388 cases.

The surgical case load by casualty demographic and proportion of primary vs. secondary surgery is shown in Figure 1 and Table 1.

Figure 2 shows the proportion of deaths; overall surgical workload; and proportion of secondary cases by casualty nationality.

The case fatality rate of 96 deaths per 10,891 cases was evaluated by demographic. The analysis of case fatality rates showed that civilian casualties were more likely to die (1.5%) than were combatants (0.8%) (Fig.2: 1.5% vs. 0.8%; $z=-3.657$; $p<0.001$) (proportion of civilian casualties (Table 1: n=2747) who Died of Wounds (DOW) (n=41) [41/2747 (1.5%)] compared to combatant group (Table 1: n=5641) who DOW (n=45) [45/5641 (0.8%) [nationality DOW not documented (n=10)].

Mechanism of Injury of casualties that DOW (n=96): GSW n=37; blast n=49; NBI n=1 appendectomy; burn n=1. Some of the casualties that DOW were during secondary cases (n=8; mechanism of injury not documented).

The ratio of primary to secondary surgery (total surgical cases n=10,891) was 1.1:1(n=5632 primary cases; n= 5259 secondary cases) (Fig. 3.).

One third of surgical cases carried out were on civilian casualties (ratio 2: 1) (n=5641:2747) (Table 1).

Overall, significantly more definitive, secondary surgery (57.3%) was carried out on civilian casualties, compared to primary surgery (42.7%) (Table 1: 57.3% vs. 42.7%; $z=-10.377$; $p<0.001$).

Within the civilian casualty population, civilian adults (CIV) had a significantly higher proportion of secondary surgery (31.1%), as did the paediatric population (7.2%), compared to primary surgery (Table 1: 31.1% vs. 21.0%; $z=-10.558$; $p<0.001$) (Table 1: 7.2% vs. 5.1%; $z=-4.014$; $p<0.001$).

In addition, within the combatant population, Enemy Forces (EF) exhibited a significantly higher proportion of secondary, more definitive surgery (12.5%) compared to primary (Table 1: 12.5% vs. 5.1%; z=-12.058; p<0.001).

Within the combatant population, International Security Assistance Forces had a significantly higher proportion of primary surgical cases compared to secondary (46.4%; 27.1%; z=18.264; p<0.001).

Overall, as a proportion of the combatant casualty population, significantly more primary surgery (57.3%) occurred compared to secondary surgery (Table 1: 57.1% vs. 43.0%; z=14.977; p<0.001).

Disease Non-Battle Injury (DNBI):

Overall there were 811 primary surgical cases on DNBI casualties (incl. Road Traffic Accidents RTAs and bites), 825 total DNBI cases (incl. secondary cases).

DNBI surgical cases accounted for 14.4% of the primary surgical cases (n=811; n=5632 primary surgical cases) or 7.6% of total surgical workload (n=825; n=10,891 total surgical cases). The DNBI burden is significantly greater than previously recorded, as a proportion of total operations (surgical cases); Jacobs et al., (2012) 6.3% (Table 1: 272/4276) and Ramasamy et al., (2010) 5.0% (Table 1: 84/1668) (7.6% vs. 6.3%; z=2.781; p<0.05) (7.6% vs. 5.0%; z=3.812; p<0.001).

Ratio of primary BI cases: primary DNBI surgical cases 5.9:1 (4821:811) or 1 in 6.9 primary cases were DNBI (Fig.3).

Combatants accounted for 74.7% of DNBI surgery and 1 in 6.9 cases were DNBI. The most common DNBI procedure was appendectomy [3.1% of all surgical cases (335/10,891)], compared to Jacobs et al., (2012), 2.5% (3.1% vs. 2.5%; z=1.971; p<0.05).

The proportion of secondary surgery; overall surgery; DNBI surgery and BI surgery per casualty nationality was analysed (Fig. 4). The combatant population accounted for 80.5% of the overall combatant burden of DNBI cases, of which ISAF accounted for 74.7% (Fig.4).

Top 5 primary DNBI surgical procedures in Armed Conflict Fig 5:

The top 5 DNBI surgical procedures were:

- Appendectomy: n=323 (of the total 335 some secondary cases not classified as DNBI)
- Abscess related procedures: n=285
- Surgical Management of Bite Wounds incl. washout and debridement: n=24
- Testicular torsion; orchidopexy procedures: n=20
- Hernia repair: n=17

The above procedures accounted for over 80% of DNBI procedures. The remaining 20% included the following life-saving surgical interventions in the cases of: Road Traffic Accident n=12; suspicious skin lesion excision n=11; Endoscopic procedures, n=9; Circumcision n=5; Ulcer repair n=3; Haemorrhoidectomy n=2; tonsillectomy n=1; and management of ruptured hydatid cyst n=1.

There was a significant increase in appendectomies accounting for 3.1% of all cases (n=335 of 10,891), compared to Jacobs et al., (2012), 2.5% of cases in previous years of the Afghanistan conflict (3.1% vs. 2.5%; z=1.971; $p<0.05$).

Sexual health-related surgical management accounted for 1.6% (n= 13) of DNBI surgery: There were 2 ectopic pregnancy procedures and 2 salpingo-oophrectomy cases; 2 salpingectomies. 3 labial abscesses, 1 c-section, 3 anal warts surgically managed.

Female casualties: In total there were 12 cases recorded as female (8 CIV and 4 PAED). Therefore (12 + 10 female procedures above – excluding anal warts where sex not recorded – there were 22 cases or 0.02% of cases were on female casualties).

Civilian: Paediatric (PAEDS): Fig 6

The top 10 humanitarian surgical procedures on paediatric casualties are shown in Fig. 6.

Paediatric cases accounted for 6.1% of the surgical cases (operations) (n=511; of 8388 nationality documented) (Table 1).

Paediatric casualties were primarily wounded by blast, accounting for 24.5% (n=125), then GSW 14.3% (n=73); and burns 11.5% (n=59).

Paediatric casualties accounted for 26% of total burns related surgery (paediatric burns n=59; total burns n=227)

The top 10 surgical procedures for paediatric casualties are also shown in Fig.6: The top 5 paediatric surgery procedures were: washout and debridement of wounds; laparotomy; burns; amputations and reconstruction techniques.

The classification of primary surgery by anatomical region of injury, as compared between ISAF combatant casualties (wearing body armour) and Humanitarian casualties, is depicted in Table 2.

<u>Primary regions of Paediatric Trauma (Table 2):</u>

1. Face: 31.1%

The most common region of paediatric surgery was the face.

Paediatric casualties suffered significantly greater facial trauma (31.1%) than civilian adult (17.2%), and ISAF casualties (15.4%) (Table 2: 31.1% vs. 17.2%; z=-4.678; p<0.001) (Table 2: 31.1% vs. 15.4%; z=-5.922; p<0.001).

2. Bilateral Lower Extremities (BLE): 23.4%

Paediatric casualties suffered significantly greater BLE trauma than civilian adults (16.0%) (Table 2: 23.4% vs. 16.0%; z=-2.619; p<0.01). There was no significant difference compared to ISAF (27.1%) (Table 2: 23.4% vs. 27.1%; z=1.183; p>0.05).

3. Abdominal Cavity (AC): 22.1%

Paediatric casualties suffered significantly greater abdominal cavity injuries compared to ISAF (12.6%) (Table 2: 22.1% vs. 12.6%; z=-3.930; p<0.001). There was no significant difference compared to civilian adults (16.1%) (Table 2: 22.1% vs. 24.5%; z=0.753; p>0.05).

4. Torso Wall (TW): 18.9%

Paediatric casualties suffered significantly greater Torso Wall trauma compared to ISAF (7.9%) (Table 2: 18.9% vs. 7.9%; z=-8.818; p<0.001). There was no significant difference compared to civilian adults (16.1%) (Table 2: 18.9% vs. 16.1%; z= -1.608; p>0.05).

5. Left Upper Extremity trauma: 10.3%

When we analyse trauma to the head, we see that paediatric casualties had significantly more head trauma compared (3.2%) compared to ISAF (0.2%) and civilian adults (0.4%) (Table 2: 3.2% vs. 0.2%; z=-6.052; p<0.001 and 3.2% vs. 0.4%; z=-3.915; p<0.001).

There were significantly more eye paediatric trauma cases (1.4%) compared to ISAF casualties (0.2%) and civilian adults (0.4%) (Table 2: 1.4% vs. 0.2%; z=-3.017; p<0.01 and 1.4% vs. 0.4%; z=-1.753; p<0.01).

Paediatric casualties had significantly fewer neck injuries (1.4%) than ISAF (4.3%) or civilian adults (4.7%) (Table 2: 1.4% vs. 4.3%; z=2.090; p<0.05 and 1.4% vs. 4.7%; z=2.239; p<0.05).

Overall, paediatric casualties had significantly fewer junctional zone injuries (2.9%) (neck; axilla; groin) compared to ISAF or civilian adults (Table 2: 2.9% vs. 6.5%; z=2.121; p<0.05 and 2.9% vs. 7.0%; z=2.277; p<0.05).

<u>Civilian: Local Adult Population (CIV; INTERP) Fig. 7:</u>

Injuries to the civilian adult population (CIV), including interpreters (INTERP), were predominantly caused by Blast (22%); GSW (17.7%); with 4.7% caused by DNBI (n=105 (including bites and RTA).

Civilian adults (CIV and INTERP) accounted for 26.6% of the total surgical workload (Table 1: CIV + INTERP n=2236; total cases demographically recorded n=8388).

The top 10 surgical procedures for Civilian adults (CIV and INTERP) are shown in Fig.7.

The top 5 surgical tool-box procedures for CIV and INTERP were: washout and debridement of wounds; laparotomy; amputation; skeletal stabilisation (external fixator/traction pin) and surgical removal of foreign bodies, such as fragmentation.

There was a significantly greater proportion of CIV secondary procedures (31.1%) compared to primary procedures (21.0%) (Table 1: 31.1% vs. 21.0%; z=-10.558; p<0.001).

<u>Primary Civilian adult regions of trauma (Table 2):</u>

1. Abdominal cavity 24.5%

The most common region of civilian adult trauma was the abdominal cavity.

Civilian casualties suffered significantly more abdominal cavity trauma (24.5%) compared to ISAF, wearing body armour (12.6%) (Table 2: 24.5% vs. 12.6%; z-8.191; p<0.001).

Paediatric casualties (22.1%) suffered significantly more abdominal cavity injuries compared to ISAF casualties wearing body armour, (Table 2: 24.5% vs. 12.6%; z=-8.191; p<0.001 and 22.1% vs. 12.6%; z=-3.930; p<0.001, respectively).

2. Torso Wall: 16.1%

Civilian adults (16.1%) and paediatric casualties (18.9%) suffered significantly more trauma to the torso wall compared to ISAF casualties (7.9%) wearing body armour (Table 1: 7.9% vs. 16.1%; 18.9%; z= -6.812; -8.818; p<0.001; p<0.001).

3. Bilateral Lower Extremity (BLE): 16%

ISAF suffered significantly more Bilateral Lower Extremity trauma (27.1%) than civilian adults (16.0%) (Table 2: 27.1% vs. 16.0%; z=6.663; p<0.001); but there was no significant difference to paediatric casualties (Table 2: 27.1% vs. 23.4%; z=1.183; p>0.05). Paediatric casualties did suffer more BLE injuries (23.4%) than civilian adults (16.0%) (Table 2: 23.4% vs. 16.0%; z=-2.619; p<0.01).

4. Left Upper Extremity (LUE): 15%

Unilateral upper extremity trauma was more likely in ISAF and civilian adult casualties than Bilateral Upper Extremity (BUE) trauma:

- Unilateral upper extremity trauma was more likely in ISAF (LUE: 19.0%) and civilian casualties (LUE: 15.0%) than Bilateral Upper Extremity (BUE) trauma (ISAF: 9.0%; CIV 6.8%) (Table 2: 19.0% vs. 9.0%; z=9.204; p<0.001) (Table 2: 15.0% vs. 6.8%; z=5.741; p<0.001).
- Unilateral upper extremity trauma was more likely in ISAF (RUE: 17.4%) and civilian casualties (RUE: 13.3%) than Bilateral Upper Extremity (BUE) trauma (ISAF: 9.0%; CIV 6.8%) (Table 2: 17.4% vs. 9.0%; z=7.926; p<0.001) (Table 2: 13.3% vs. 6.8%; z=4.717; p<0.001).

There was no significant difference between left and right upper extremity trauma:

- ISAF: LUE vs. RUE (Table 2: 19.0% vs. 17.4%; z= 1.324; p>0.05)
- Civilian adults: LUE vs. RUE (Table 2: 15.0% vs. 13.3%; z=1.064; p>0.05)

5. Right Lower Extremity (RLE): 14.7%

When we analyse the junctional areas of injury requiring surgical intervention, there is a significant increase in neck trauma between civilian adults (4.7%) and ISAF (4.3%) compared to paediatric casualties (1.4%) (Table 2: 4.7% vs. 1.4%; $z=2.239$; $p<0.05$).

In addition, there was significantly less Bilateral Upper Extremity (BUE) (6.8%) trauma in civilian adult casualties compared to ISAF population (9.0%) (Table 2: 6.8% vs. 9.0%; $z=2.032$; $p<0.05$).

<u>Combatants: International Security Assistance Force (ISAF)</u>

<u>Primary ISAF regions of trauma:</u>

1. Bilateral Lower Extremity (BLE) trauma (27.1%) was the most common region of ISAF trauma, and was significantly more compared to civilian and paediatric casualties (Table 2).

ISAF casualties underwent significantly more proximal vascular control procedures (9.2%) compared to humanitarian surgery carried out on civilian adults (5.5%) and paediatric casualties (4.5%) (Table 1: 9.2% vs. 5.5%; $z=3.470$; $p<0.001$ and 9.2% vs. 4.5%; $z=2.355$; $p<0.05$).

ISAF casualties suffered significantly more perineal injuries (6.7%) compared to civilians adults (3.4%) or paediatric casualties (3.2%) (Table 2: 6.7% vs. 3.4%; $z=3.641$; $p<0.001$).

ISAF suffered significantly more Bilateral Lower Extremity trauma (27.1%) than civilian adults (16.0%) (Table 2: 27.1% vs. 16.0%; $z=6.663$; $p<0.001$); but there was no significant difference compared to paediatric casualties (Table 2: 27.1% vs. 23.4%; $z=1.183$; $p>0.05$).

2. Left Upper extremities: 19%
3. Right upper extremity: 17.4%

ISAF, suffered significantly more LUE (19.0%) and RUE (17.4%) injuries compared to civilian adults (Table 1: 19.0% vs. 15.0% $z=2.668$; $p<0.01$ and 17.4% vs. 13.3%; 2.842; $p<0.01$).

ISAF suffered significantly more Bilateral Upper Extremity injuries (9.0%) compared to ANSF (Table 1: 9.0% vs. 6.8%; $z=2.032$; $p<0.05$).

4. Face: 15.4%

There was significantly less facial trauma in combatant ISAF (15.4%) compared to paediatric casualties (31.1%) (Table 2: 15.4% vs. 31.1%; -5.922; $p<0.001$).

5. Right and Left lower extremities: 14.9% respectively

There was significantly greater perineal trauma between ISAF (6.7%) and civilian adult casualties (3.4%) (Table 2: 6.7% vs. 3.4%; $z=3.641$; $p<0.001$).

There was significantly greater Bilateral Upper Extremity (BUE) trauma in ISAF (9.0%) compared to civilian adult casualties (6.8%) (Table 2: 9.0% vs. 6.8%; $z=2.032$; $p<0.05$).

Of "Junctional Zones", the neck was significantly more commonly affected in combatants (ISAF) (4.3%) and adult civilian groups compared to groin (1.7%) and axilla (0.5%).

Combatant ISAF casualties suffered the same proportion of junctional zone injuries (6.5%) compared to civilian adults (Table 2: 6.5% vs. 7.0%; $z=0.511$; $p>0.05$).

There was no significant difference between the rates of head injuries between ISAF, wearing body armour, (0.2%) and civilian adults (0.4%) (Table 2: 0.2% vs. 0.4%; $z=-0.994$; $p>0.05$).

ISAF casualties (0.2%) suffered the same number of eye injuries as civilian adults (Table 2: 0.2% vs. 0.4%; $z=-0.994$; $p>0.05$).

There was no significant difference between hand trauma; buttock trauma; pelvis; Left Lower Extremity (LLE) and Right Lower Extremity (RLE); axilla; groin and Chest Cavity (CC); between populations (Table 2).

Discussion

The future of combat operations is likely to be typified by prolonged evacuation chains, fewer surgeons, more austere environments and exaggerated timelines for care (Schwab, 2015). We must analyse the surgery performed from the most recent modern conflict to ascertain the provision for the future. The surgeon operating in conflict zones, might expect to manage Battle Injury (BI); DNBI; and carry out humanitarian surgery on the local adult population, as well as well as paediatric casualties and combatants alike, all of which present their own unique surgical burden of war.

In the Afghanistan conflict 2009-2014, paediatric casualties accounted for 6.1% of surgical workload and civilian adults 26.6% (Table 1, Fig.1). The civilian casualties accounted for a larger proportion of secondary surgical cases when compared to their proportion of primary cases (EF; INTERP; CIV; PAEDS) (Fig. 1, Table 1: secondary cases: 57.3%). The same proportion of primary to secondary surgical cases is seen in the ANSF cohort of cases (Fig.1, Table 1). The inverse was found when compared to ISAF surgical cases, where the proportion of primary surgery was greater than secondary (Fig. 1, Table 1). Possible explanations for this finding are that civilian casualties requiring surgical intervention were subsequently sent back to local health care facilities/community, whereas ISAF casualties were repatriated and underwent definitive surgical management in host/allied nations. This possibly suggests that the health-care system realised that civilian casualties would be returned to remote environments upon discharge, they stayed longer at the facility in Afghanistan in order to receive more intensive care. Another possibility is that locals were more seriously injured due to their lack of body armour.

This study shows that civilian casualties are more likely to die in Armed Conflict than are combatants (Fig. 2). Previous studies have described that truncal haemorrhage (thorax; abdomen and pelvis) accounted for the majority of preventable deaths (Eastridge et al., 2012). The present study shows that civilian adults and paediatric casualties, not wearing body armour, had statistically more abdominal cavity surgery compared to ISAF, wearing body armour (Table 2) (see also Eastridge et al., 2012). We show significantly greater neck trauma in ISAF and CIV groups, compared to paediatric casualties (Table 2). Why this might occur is unknown, however children have anatomically smaller necks in proportion to their more exposed head. Children also suffered a significant increase in head trauma compared to adult casualties (Table 2: 3.2%) compared to ISAF (Table 2: 0.2%) or civilian adults (Table 2: 0.4%). Facial injuries accounting for 31.1% of paediatric trauma surgery. There was no significant difference in head surgery between ISAF wearing helmets and civilian adults, which suggests that the reason for significantly more head trauma in paediatric casualties is not related to body armour.

The case fatality rate was highest in civilian casualties as a proportion of surgical cases and the local civilian adult population suffered the greatest proportionate loss of life (Fig.2). Civilian adults and paediatric casualties suffered significantly more abdominal trauma, and torso wall injuries, than ISAF (Table 2), perhaps due to the lack of body armour.

Previous studies reported that injured civilians who made it to Camp Bastion Role 3 facility had less severe injuries than those reported here. It is postulated that those with severe injuries died en-route to the Camp Bastion facility, or perhaps it is the level of care that they receive at role 3 that is paramount (Coupland, 1991; Benov et al., 2013; Tai et al., 2008).

We found that the case fatality rate of civilian casualties (Civilian adults; paediatric; interpreters) was 1.5%, compared to combatants 0.8% (ISAF; ANSF; EF); perhaps as civilians lacked body armour, their injuries were more severe. The mechanism is unknown, but could perhaps be attributable to a lower baseline physiological reserve given that some may well have been malnourished, or dehydrated, or have had co-morbidities at the time of trauma.

The results of the present study differ from a previous study by Benov et al., (2014) who examined the Syrian Civil Conflict and the surgical care provided by the Israeli defence forces (IDF) to injured persons seeking medical care at the Israeli border. The Benov study describes the components of surgical intervention as incorporating pre-hospital; humanitarian; civilian; combatant care (Benov et al., 2014). Abdominal and thoracic injuries (taken to mean "truncal injuries") were the most frequently injured regions in their study, although their study proposed that there were naturally selected survivors, and that this may have biased their results (Benov et al., 2014; Rasmussen 2013).

For the first time the present study describes, in detail, the surgical management of DNBI. We show that the overall DNBI surgical burden is 7.6% of total surgical cases, or 14.4% of primary surgery. When compared to previous studies, as a proportion of the total surgical cases (operations), the DNBI burden is significantly greater than previously recorded: Jacobs et al., (2012) 6.3% (Table 1: 272/4276) and Ramasamy et al., (2010) 5.0% (Table 1: 84/1668) (7.6% vs. 6.3%; $z=2.781$; $p<0.05$) (7.6% vs. 5.0%; $z=3.812$; $p<0.001$).

The present study investigated further the DNBI cases by casualty nationality and as 74.7% of DNBI surgery are ISAF, despite changes in warfare and weapons technology, we anticipate soldiers in the future, will require the similar provision of DNBI surgery as outlined in this study (Fig. 4). We suggest that the most frequent DNBI surgical procedures (Fig. 5) be used as a template for future conflicts.

In the present study, on average, 1 in 13 cases in Armed conflict was DNBI (Total cases n=10,891; DNBI n=825), and 74.7% of DNBI cases were ISAF (Fig. 3). The DNBI: BI ratio of surgery peaked at one in every 6.9 primary cases was a DNBI surgical case (Fig. 3). However, Belmont et al., (2010) showed that hospital admissions and evacuations for DNBI vs. BI was as high as 1:1.75 in 2007 during the height of the conflict in Afghanistan.

In our study, the most common non-battle injury (DNBI) procedure was appendectomy followed by surgical management of abscesses, testicular torsion/orchidopexy procedures; surgical management of bites and hernia repair procedures (Fig.5). DNBI accounted for 3.1% of all cases, a significant increase ($p<0.05$) compared to 2.5% of cases reported for the Afghanistan conflict by Jacobs et al., (2012). Ramasamy et al., (2010) however found that Incision and Drainage (I&D) of abscesses was the most common DNBI.

This is the first study to reveal the impact of female casualties and sexual health on the surgical workload in armed conflict. Less than 0.02% of surgical procedures was on female casualties. Sexual health-related surgical management accounted for 1.6% (n= 13) of DNBI surgery: There were 2 ectopic pregnancy procedures and 2 salpingo-oophrectomy cases, 2 salpingectomies, 3 labial abscesses, 1 caesarean section. Anal warts were surgically managed in 3 cases (sex not recorded) and 5 circumcisions were carried out. It is not known whether female casualties were over, or under, represented as a proportion of the female to males deployed at that time.

The highest proportion demographically of DNBI was accounted for by combatants (predominantly ISAF 74.7%) (Fig.4). The ratio of surgery performed on combatants (ISAF; ANSF; EF) to Humanitarian (PAEDS; CIV; INTERP) was 2:1 (Fig.4).

In future armed conflicts the surgical skill set for conflict remains broad, and not just related to BI which gains the majority of the focus. Life-saving surgical interventions carried out in Afghanistan demonstrate the importance of a broad skill-set which includes the following: Salpingectomy, oophorectomy and surgical management of ectopic pregnancy; Ulcer repair;

Hemorrhoidectomy; Caesarean; circumcision; excision of genital warts; Tonsillectomy and management of ruptured hydatid cyst.

The most frequently performed DNBI surgical procedures performed during 2009-2014 (Fig.5) demonstrates that surgeons operating in future modern conflict zones must be prepared to manage a broad range of surgical needs, including: appendectomy open and laparoscopically; abscesses in any region of the body; bites (human, snake, dog); testicular torsion incl. orchidopexy; and hernia repair. We suggest Fig.5 provides a starting template for DNBI surgical procedures required in future armed conflicts.

We have described which body regions of trauma were operated upon and have detail casualty demographics (Table 2). This has not been previously shown. The findings of our study potentially highlight the positive effect of Personal Protective Equipment (PPE) on trauma as we can see statistically significant differences in the proportion of trauma to body regions e.g. the torso and abdominal cavity, being higher in civilian adults and children compared to ISAF. This suggests that the body armour helped to significantly reduced abdominal and torso wall injuries.

Previous studies have shown the multiplicity of wounding caused by explosions, and the polytrauma patient this presents (Chapter 1: Maitland et al., 2016). The present study translates polytrauma into specific anatomical regions where surgery was carried out and clearly shows that upper extremity trauma is significantly more unilateral and lower extremity trauma is significantly more bilateral in nature (Table 2). We also show that Bilateral Lower Extremity trauma was significantly greater in Paediatric casualties than civilian adults, a clear hazard of growing up in a war zone. And, unilateral upper extremity trauma was more common in civilian adults and ISAF casualties than was bilateral upper extremity trauma (Table 2). Adult civilians and ISAF, all are more likely to have bilateral lower extremity injuries than unilateral (Table 2). These are striking results, but at this stage we do not have plausible explanations. Clearly, this highlights an area for further study.

Edwards et al., (2012, 2014), analysed the paediatric surgical interventions through Iraq and Afghanistan from 2002 – 2010. The present study hopes to extend the analysis into the later stages of the conflict in Afghanistan up until the end of NATO's official engagement there. Edwards et al., (2012, 2014) showed that head injuries were high in the younger age group of (4-14 years) compared to adults, and that between the ages of 9-14 years, children were more likely to have thoracic procedures carried out on them than adults. The study also outlined that the most common paediatric surgical procedures were soft tissue debridement; vascular procedures; laparotomy and thoracostomy procedures. We suggest, therefore, that Figure 6 provides an initial template for paediatric surgery required in future armed conflicts.

This is the first study to reveal the impact of humanitarian surgery on secondary surgery (Table 1). Humanitarian surgery (civilian adults; interpreters; paediatric casualties) accounted for 57% of secondary surgery (Fig. 1; Fig.2). The most common region of paediatric trauma was the face (31.1%) (Table 2). Facial trauma occurs significantly more frequently in the young compared to civilian or combatant adult casualties (Table 2). Paediatric neck trauma occurs in a disproportionate, and significantly lesser extent than it does in the adult casualties (civilian and ISAF) (Table 2). Edwards et al., (2012, 2014) has also shown that paediatric casualties have significantly fewer surgical intervention to the junctional area of the neck, compared to adults (civilian and ISAF). This suggests that another reason, other than body armour, accounts for the wounding pattern and for why children have fewer junctional injuries, especially the neck, compared to adults (regardless of body armour), and also for head injuries.

Edwards et al., (2012, 2014) described surgery for head injuries being more common in 4-14yr old patients than in older patients. We show, however, that surgery for head injuries is statistically higher in the paediatric group. Paediatric casualties accounted for 26% of total burns related surgery (Table 2). This has not been previously documented. There was no significant difference in paediatric casualties who suffered high rates of extremity trauma overall (Table 2).

There have been few studies on the surgical management of paediatric trauma in Afghanistan. Between 2009 and 2015, 3746 children died, and 7904 children were injured as a result of armed conflict within Afghanistan (Edwards et al., 2012, 2014; Thompson et al., 2017; Reeves et al., 2018). Our study fills the gap in the data available for the latter half of the conflict. The experience of NGOs and other Armed Forces operating in conflict zones highlights additional surgical skill set considerations. For example, the experience with antipersonnel mines of the International Committee of the Red Cross (ICRC) outlined that the surgical decision to amputate, or salvage is often underestimated (Coupland 1991). The effect of the cultural/religious unacceptability of amputation requires additional considerations on surgical care provision for civilians and combatants, (present study; Coupland 1991). This imposes a unique burden on the surgeon operating in conflict zones and is currently not fully analysed.

Very few studies have evaluated the impact of civilian casualties on surgical provision in war. The present study shows that 57% of secondary surgical cases were carried out on civilians (Table 1; Fig.1; Fig.2) and because approximately half of all surgery was secondary (Fig.3), this is a high surgical workload. Possible reasons for this include: ISAF or military cases for medevac underwent further operations elsewhere. Only local patients must undergo the full treatment on-site. The pathology might demand more than one procedure, and the health state of the patient prior to injury may demand damage control surgery with more than one procedure.

We found that surgical cases involving paediatric trauma was generally in keeping with previous studies, but with a few important details. The proposed template for surgical procedures on paediatric casualties is outlined in figure 6. Over ¼ of all surgical burn procedures carried out on the 10,891 surgical cases analysed, was on paediatric casualties, a detail not highlighted in the study by Edwards et al., (2012, 2014). Paediatric facial trauma required more surgical intervention than any other region (Table 2). Our finding that debridement and washout procedures remained the most common surgical procedure on paediatric casualties in conflict zone was consistent with previous studies (Edwards et al., 2012, 2014; Thompson et al., 2017), closely followed by paediatric laparotomy surgical procedures and paediatric amputations. These findings differ from Edwards et al., (2012, 2014) in that there were fewer thoracic surgical interventions, and vascular procedures, carried out between 2009-2014. Arul et al., (2012) found that extremities were the most commonly affected paediatric region but the numbers in their study were small (85) and amputations weren't listed in their summary of surgical procedures which were carried out.

The present study shows that 6.1% of all surgical cases were on paediatric casualties compared to 14.7% in Ramasamy et al., (2010) and 5.1% in Iraq (Coppola et al., 2006; McGuigan 2006) and 6% found by Jacobs et al., (2012). In addition, in the present study, 56.6% of paediatric surgical cases were secondary operations and that the paediatric surgical tool box for conflict in order of frequency of occurrence (Fig. 6) is: soft-tissue debridement; laparotomy; surgical management of burns; paediatric amputations and reconstruction procedures.

A recent study showed the mean transport time from point of injury to a Role 2 facility was 198 minutes in Afghanistan (Reeves et al., 2018). In future there will likely be prolonged extraction times for all casualties in conflict zones and combat surgeons will need to have a broad skill set to deal with complex trauma and Battle injuries sustained on allied forces, but they also must care for the local population and DNBI as discussed above.

Within war-torn regions, non-governmental aid organisations (NGOs) traditionally support host nation facilities and Armed Forces deployed surgeons (Ramasamy et al., 2010). As the nature of modern-conflict changes, together with the possible inclusion of peace-keeping operations (e.g. Syria), it's not an unlikely scenario that an NGO surgeon might find themselves performing emergency BI and DNBI procedures such as the loop colostomy for an imperforate anus, as well as for incarcerated hernias or a pyloric stenosis. Indeed, the surgical skill set required for such paediatric conditions may never have previously been seen, or performed, by the typical surgeon (Schwab 2015). Porta et al., (2013) presented the results of a survey from surgeons that deployed to Iraq and Afghanistan who reported that 30% of those who responded to the survey performed procedures they hadn't done before, which is clearly a concern.

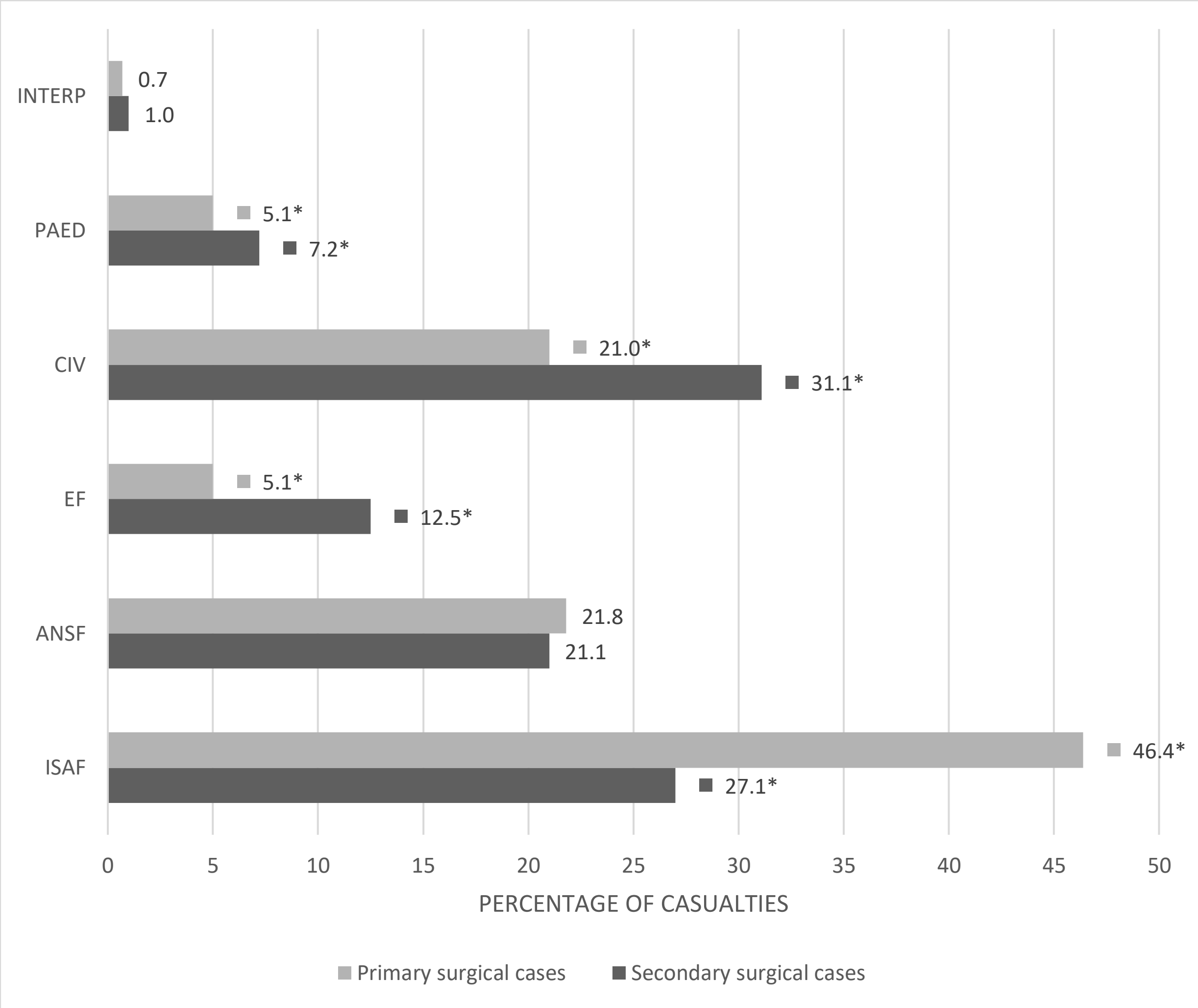
The humanitarian surgery most frequently called upon to treat adult civilian casualties was: debridement and washout of wounds; laparotomy; amputations; skeletal stabilisation: external fixator/pin; and operations to remove foreign bodies from blast injuries (e.g. fragmentation) (despite there being only a limited indication for removal of foreign bodies). We suggest that Figure 7 provides an initial template for the civilian surgery that is most likely to be required in future armed conflicts and/or terror attacks.

The present chapter provides a template for DNBI surgery in conflict (Fig. 5), as well as the template for humanitarian surgery (Fig. 6; Fig.7) on civilians, caught in the ravages of war, and in doing so goes some way to inform future planning for surgical provision in conflict zones.

The surgical procedures performed will be itemised and categorised into respective anatomical regions of trauma, and analysed in the next chapter (Chapter 6).

Figures and Tables:

Figure 1: Relationship between casualty nationality and surgical activity



*significantly different (p<0.001)

Fig.1 Relationship between casualty nationality and primary (n=4394) vs. secondary (n=3994) surgical caseload as a proportion of nationality of casualties. Casualty nationality: ANSF (Afghan National Security Force); CIV (Civilian Adults); EF (Enemy Forces); PAEDS (Paediatric); INTERP (Interpreters); ISAF (International Security Assistance Force) (see Table 1 for further data).

Figure 2: Relationship between casualty nationality and case fatality

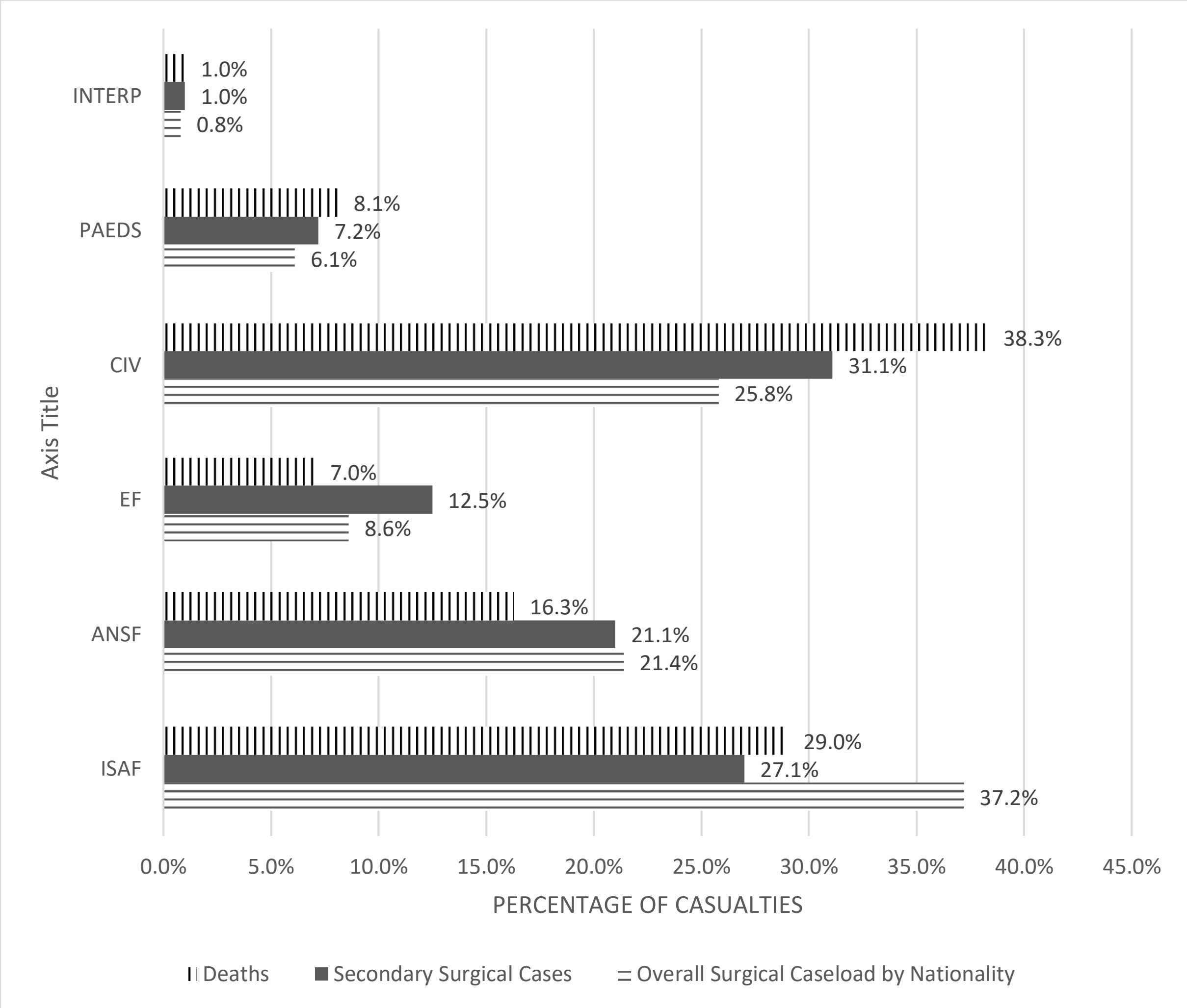


Fig.2 Relationship between casualty nationality and case fatality; secondary surgical caseload and overall surgical caseload as a proportion of casualties. Proportion of case fatalities (deaths n=96) per casualty nationality; proportion of secondary surgical cases per casualty nationality (n=3994); proportion of overall operations (caseload) (n=8388). Casualty nationality: ANSF (Afghan National Security Force); CIV (Civilian Adults); EF (Enemy Forces); PAEDS (Paediatric); INTERP (Interpreters); ISAF (International Security Assistance Force) (see Table 1 for further data).

Figure 3: Classification of surgery

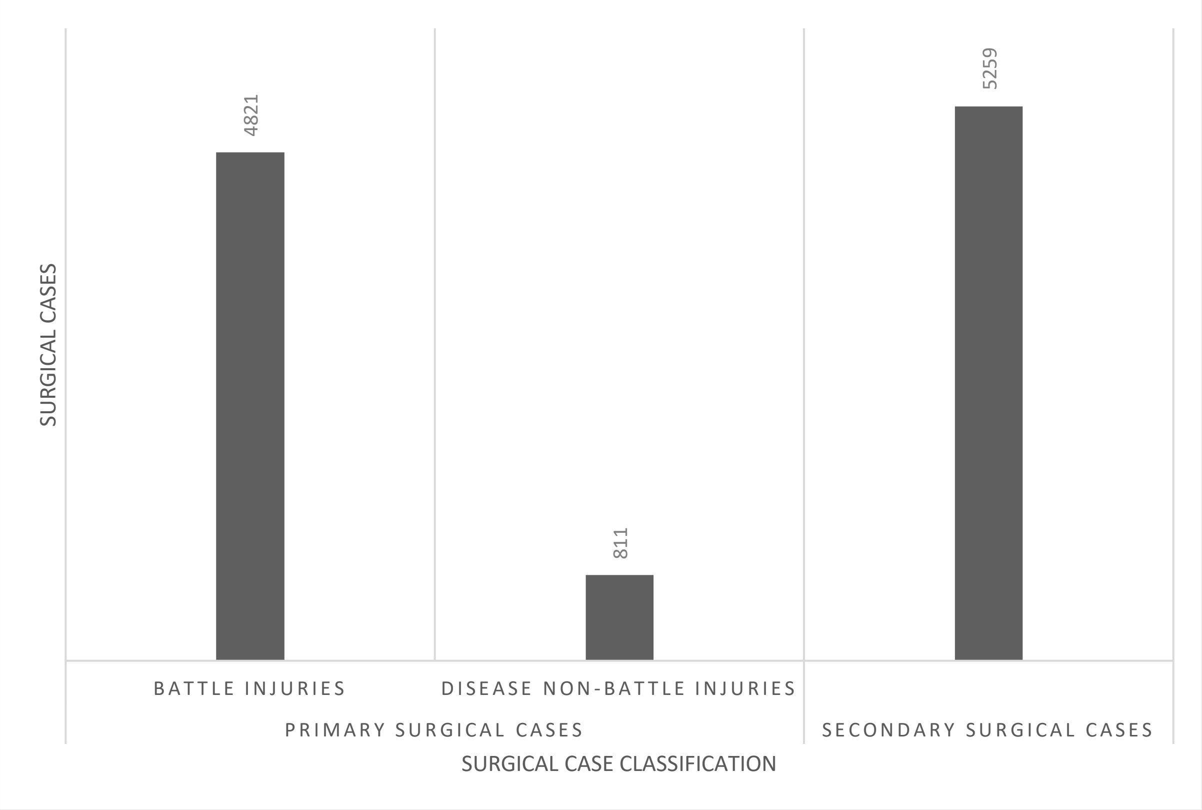


Fig. 3 Type of surgical activity as a proportion of total surgical cases (n=10,891) per classification of operation [primary surgery (n=5632): Battle Injury (BI) (n=4821); Disease Non-Battle Injury (DNBI) (n=811), and secondary surgery (n=5259)]. Ratio of BI to DNBI 5.9:1. Ratio of Primary to Secondary surgical cases 1.1:1.

Figure 4: Relationship between casualty nationality and injury type

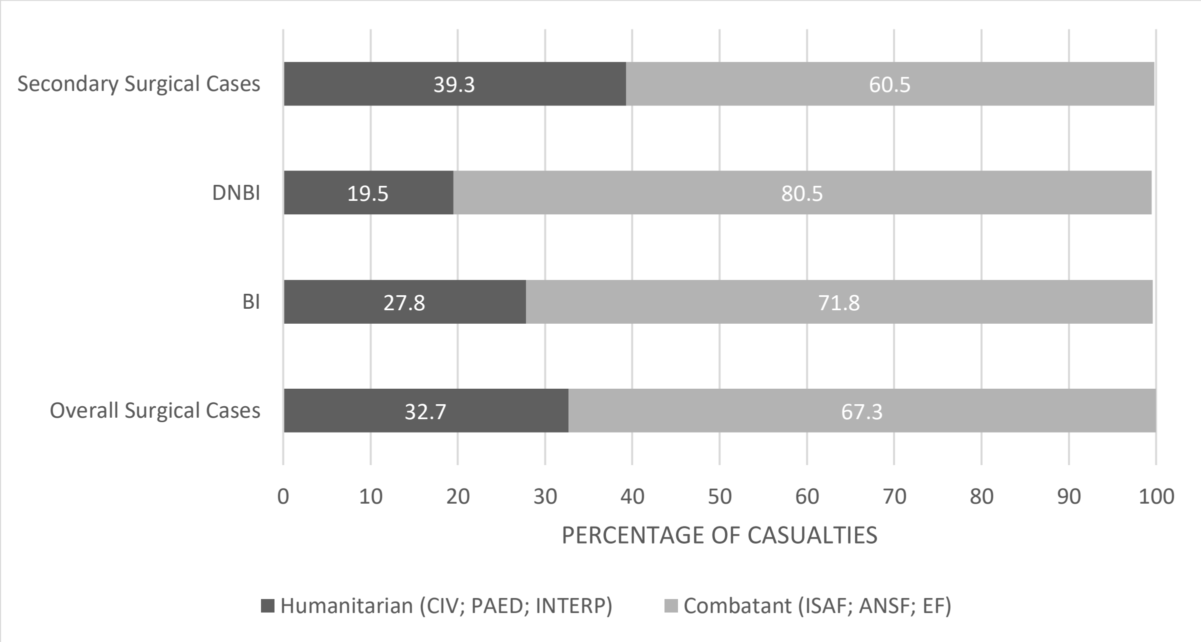


Fig.4 Relationship between casualty nationality and surgical burden (caseload) as a proportion of overall surgical cases (n=10,891); secondary surgical cases (n=5259); primary DNBI (Disease Non-Battle Injury) (n=811) and BI (Battle Injury) (n=4821). Casualty nationality: ANSF (Afghan National Security Force); CIV (Civilian Adults); EF (Enemy Forces); PAEDS (Paediatric); INTERP (Interpreters); ISAF (International Security Assistance Force) (see Table 1 for further data).

Figure 5: Primary Disease Non-Battle Injury surgical procedures:

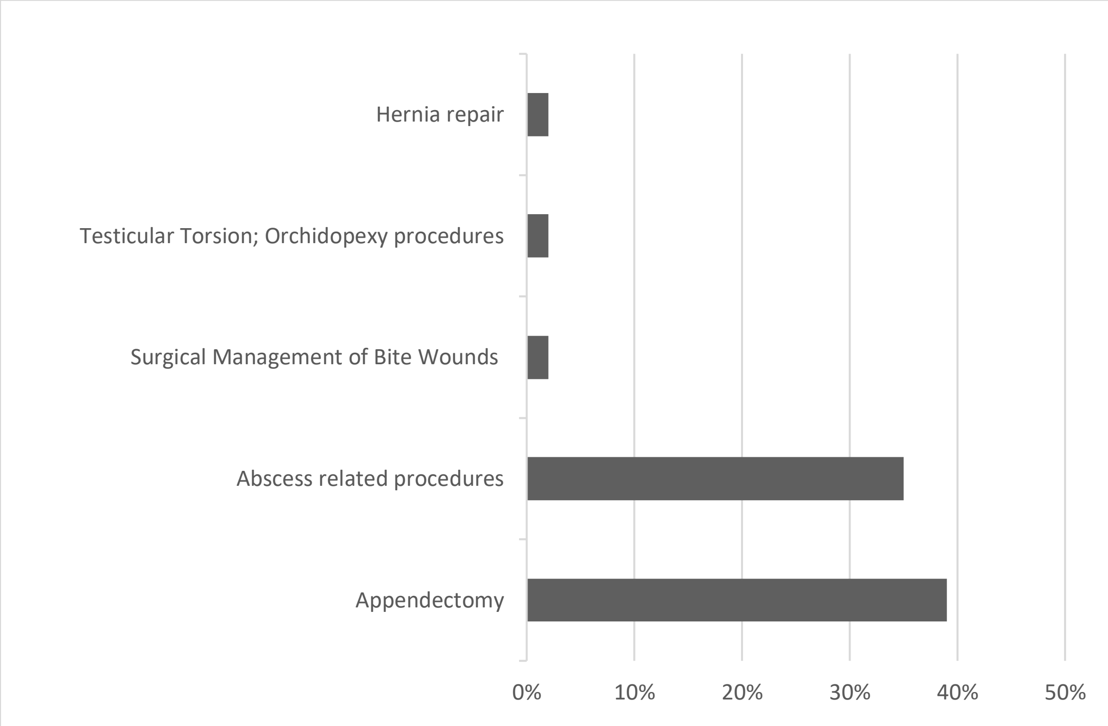


Fig. 5 Proportion of total Disease Non-Battle Injury (DNBI) cases (n=811) that involved the following top 5 DNBI surgical procedures (hernia repair n=17; Testicular Torsion and orchidopexy n=20; surgical management of bite wounds n=24; Abscess related n=285; Appendectomy n=323).

Figure 6: Primary humanitarian surgical procedures: Paediatric casualties

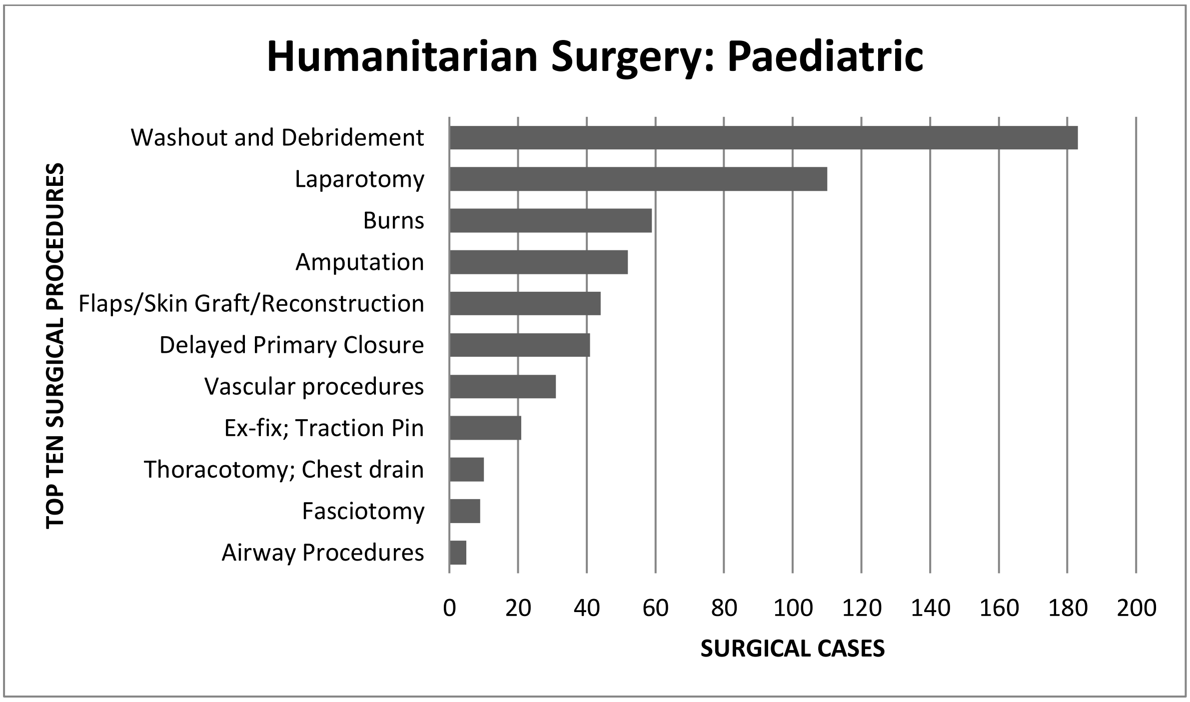


Fig. 6 Surgical procedures most frequently performed on paediatric casualties (see Table 1 for data).

Figure 7: Primary humanitarian surgical procedures: Civilian Adults including Interpreters

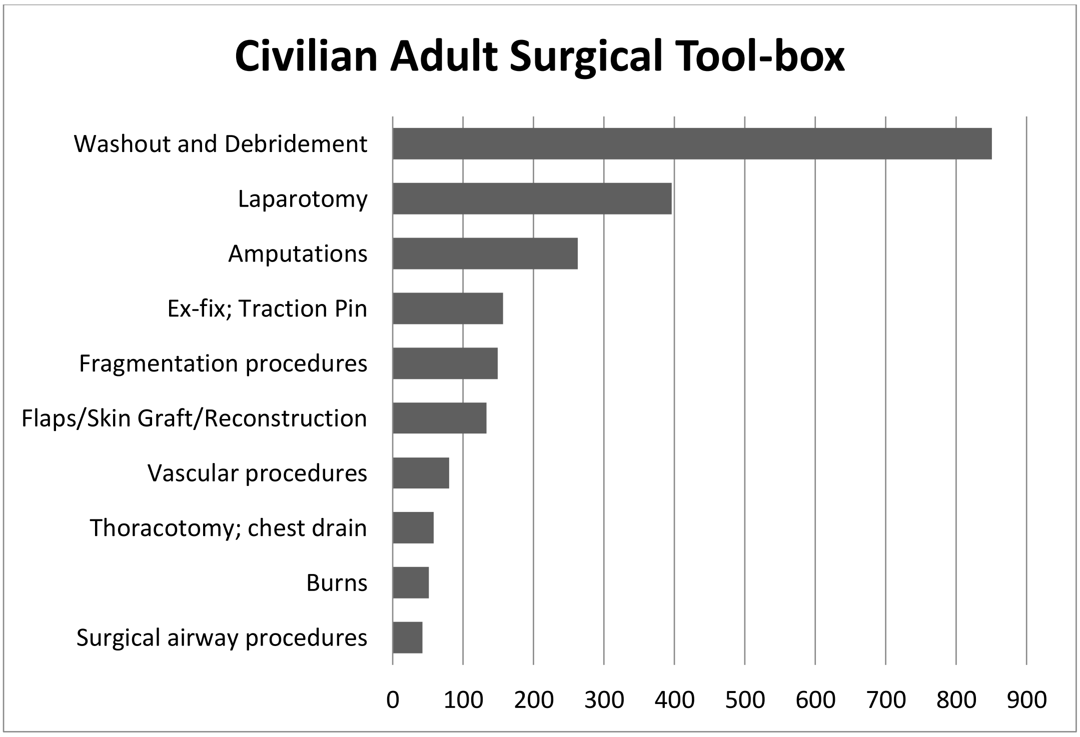


Fig. 7 Surgical procedures most frequently performed on civilian adult casualties (see Table 1 for further data).

Table 1 Relationship between civilian nationality and number of primary and secondary, surgical cases being performed between 2009-2014

Total	Casualty Nationality n=8388	Percentage of cases	Primary surgical cases n=4394	Secondary surgical cases n= 3994	z-value	p-value
Combatants	ISAF	n=3121 37.2%	n=2040 46.4%	n=1081 27.1%	18.264	0.000*
	ANSF	n=1798 21.4%	n=956 21.8%	n= 842 21.1%	0.780	0.436
	EF	n=722 8.6%	n=224 5.1%	n= 498 12.5%	-12.058	0.000*
Total	Proportion of combatants: primary vs. secondary n=5641		n=3220 57.1%	n=2421 43.0%	14.977	0.000*
Humanitarian	PAEDS	n=511 6.1%	n=222 5.1%	n=289 7.2%	-4.014	0.000*
	Interpreter	n=71 0.8%	n=30 0.7%	n = 41 1.0%	-1.501	0.133
	CIV	n=2165 25.8%	n=922 21.0%	n= 1243 31.1%	-10.558	0.000*
Total	Proportion of humanitarian surgery: primary vs. secondary n = 2747		n=1174 42.7%	n=1573 57.3%	-10.377	0.000*

[*(p<0.05)]

Table 1: Relationship between casualty nationality, and primary vs. secondary surgical activity (definitive surgery); surgical case nationality percentage of primary vs. secondary surgery on combatant population (ISAF International Security Assistance Force; ANSF Afghan National Security Force; EF enemy forces) vs. humanitarian population (PAEDS Paediatric; INTERP Interpreters; CIV Civilian Adults); Percentage of primary and secondary surgical workload by casualty nationality. Total proportion of combatant population (n=5641) and humanitarian (n=2747) per primary, and secondary surgery.

Table 2 Relationships between regions of the body operated upon, nationality of casualties, and the use of body armour.

	Combatant	Humanitarian			*(p<0.05)
	Combatant ISAF A	Civilians Adults (CIV+ INTERP) B	Paediatric PAEDS C	z-value	p values
Total cases	n=3121	n=2236	n=511		
Primary cases	n=2040	n=952	n=222		
Neck	4.3%	4.7%	1.4%	A vs. B -0.495 A vs. C 2.090 B vs. C 2.239	0.620 0.036* 0.025*
Axilla	0.5%	1.0%	0.05%	A vs. B 1.672 A vs. C 0.945	0.9461 0.345
Groin	1.7%	1.3%	1.4%	A vs. B 0.819 A vs. C 0.331	0.413 0.741
Junctional zones	6.5%	7.0%	2.9%	A vs. B -0.511 A vs. C 2.121 B vs. C 2.277	0.609 0.034* 0.023*
Chest Cavity	3.2%	4.6%	5.0%	A vs. B -1.903 A vs. C -1.410	0.5716 0.159
Abdominal Cavity	12.6%	24.5%	22.1%	A vs. B -8.191 A vs. C -3.930 B vs. C 0.753	0.000* 0.000* 0.451
Proximal Vascular Control procedures	9.2%	5.5%	4.5%	A vs. B 3.470 A vs. C 2.355 B vs. C 0.598	0.000* 0.018* 0.549

	Combatant	Humanitarian			*(p<0.05)
	Combatant ISAF A	Civilians Adults (CIV+ INTERP) B	Paediatric PAEDS C	z-value	p values
Total cases	n=3121	n=2236	n=511		
Primary cases	n=2040	n=952	n=222		
Head	0.2%	0.4%	3.2%	A vs. B -0.994 A vs. C -6.052 B vs. C -3.915	0.320 0.000* 0.000*
Face	15.4%	17.2%	31.1%	A vs. B -1.252 A vs. C -5.922 B vs. C -4.678	0.210 0.000* 0.000*
Eyes	0.2%	0.4%	1.4%	A vs. B -0.994 A vs. C -3.017 B vs. C -1.753	0.320 0.003* 0.080
LUE	19.0%*	15.0%*	10.4%	A vs. B 2.668 A vs. C 3.157 B vs. C 1.772	0.008* 0.002* 0.078
RUE	17.4%	13.3%	7.2%	A vs. B 2.842 A vs. C 3.898 B vs. C 2.505	0.005* 0.000* 0.012*
BUE	9.0%*	6.8%*	10.0%	A vs. B 2.032 A vs. C -0.42 B vs. C -1.640	0.042* 0.623 0.101
Hand	1.7%	1.10%	0.05%	A vs. B 1.254 A vs. C 1.361	0.210 0.174

	Combatant	Humanitarian n=2747			*(p<0.05)
	Combatant ISAF A	Civilians Adults (CIV+ INTERP) B	Paediatric PAEDS C	z-value	p values
Total cases	n=3121	n=2236	n=511		
Primary cases	n=2040	n=952	n=222		
Torso wall	7.9%	16.1%	18.9%	A vs. B -6.812 A vs. C -8.818 B vs. C -1.608	 0.000* 0.000* 0.108
Buttock	6.3%	5.8%	4.5%	A vs. B 0.531 A vs. C 1.062	 0.596 0.288
Perineum	6.7%	3.4%	3.2%	A vs. B 3.641 A vs. C 2.030 B vs. C 0.149	 0.000* 0.043 0.882
Pelvis	2.4%	2.0%	2.7%	A vs. B 0.684 A vs. C -0.276	 0.494 0.783
LLE	14.9%	12.4%	12.2%	A vs. B 1.830 A vs. C 1.081	 0.067 0.280
RLE	14.9%	14.70%	12.6%	A vs. B 0.143 A vs. C 1.680	 0.886 0.093
BLE	27.1%	16.0%	23.4%	A vs. B 6.663 A vs. C 1.183 B vs. C -2.619	 0.000* 0.237 0.009*

Table 2. Body regions operated upon and casualty nationality as a proxy to analyse the use of body armour on injury patterns. Proportions of primary surgery that involved combatant casualties wearing body armour [ISAF (International Security Assistance Force) (n=2040)] vs. humanitarian population [PAEDS (Paediatric) (n=222); civilian adults (INTERP Interpreters & CIV Civilian Adults (n=952)], not wearing body armour, per body region of injuries were compared. LUE (Left Upper Extremity); RUE (Right Upper Extremity); BUE (Bilateral Upper Extremities); LLE (Left Lower Extremity); RLE (Right Lower Extremity); BLE (Bilateral Lower Extremities).

Chapter 6

An anatomical approach to surgery in armed conflict

III- The categorisation of surgical procedures in conflict to save eyes; life; and limb

Abstract

Background:

The present study outlines a new approach to providing the best surgical provision in armed conflict through the development of a new categorisation of surgical interventions carried out by body region, rather than being driven by surgical specialty. The approach is developed through the analysis of the consecutive surgical procedures carried out in our most recent modern conflict in Afghanistan. This approach has enabled us to outline comprehensively, the surgical procedures by anatomical region. It also accounts for the effect on trauma surgery caused by the multiplicity of wounding associated with explosions seen in terror-related incidents occurring today.

Methods:

An analysis of operating theatre records logged between November 5, 2009, and September 21, 2014 was performed. The total surgical cases (n=10,891) performed during the latter half of the conflict in Afghanistan until 2014, the end of UK formal operations in Afghanistan at Role 3 Camp Bastion Facility were analysed, and 20,266 surgical procedures identified. Methodology differed from previous studies to account for poly-trauma, and a new categorisation of surgery by anatomical region was developed. Instead of procedures counting once per case (operation), we were able to account for surgical procedures on multiple body regions that occurred on an individual such as multiple-limb amputation. The most frequently used index surgical procedures were identified and categorised by anatomical region. The procedures were then allocated to the most appropriate surgical specialty and compared to the surgical classifications used for previous years of the conflict in Afghanistan. The combat activity, wounding patterns, surgeons, and mission emphasis of the hospital all changed throughout the conflict period. Statistical analysis using z-test for comparison of proportions was used Significance was accepted at the 5% level ($p<0.05$).

Results:

During the study period, 10,891 cases required 20,266 surgical procedures and were categorised by anatomical region to account for multiplicity of wounding and multiple anatomical regions operated on per case. We show that 3.8% of cases involved surgical intervention to the eyes (n=414). The junctional zone most operated on to gain proximal vascular control was the groin 20.8% (n=75 of 360), compared to the neck 7.2% (n=26 of 360) (carotid artery and vein, subclavian artery and vein), or axilla 6.4% (n=23 of 360) (axillary artery and veins) (20.8% vs. 7.2%; z=5.259; p<0.001) (20.8% vs. 6.4%; z=5.636; p<0.001). The abdomen was more likely to be opened 45.8% (n=165 of 360) than the chest 30.0% (n=108 of 360) to gain proximal vascular control (45.8% vs. 30.0%; z=4.369; p<0.001) (Fig. 1).

Lower extremity amputation 50.9% (n=1091 of 2142) was significantly greater than upper extremity amputation 13.0% (n=142 of 2142) (50.9% vs. 13.0%; z=26.600; p<0.001) (Fig. 1). Bilateral amputations accounted for 24.4% of amputation procedures (n=522 of 2142). We show that the most common intra-abdominal organ operated on was the intestine;10.4% of cases involved intestinal procedures (n=1137 of 10,891), and that significantly more surgery was carried out on the large bowel 37.0% (n=421 of 1137) than the small bowel 24.1% (n=273 of 1137) (37% vs. 24.1%; z=6.677; p<0.001). The next most commonly operated on intra-abdominal organs were the spleen (n=116) and liver (n=59). Casualties that underwent craniotomy/craniectomy procedure had 9.1% case fatality rate (1/11). One in 13.5 of cases involved surgery to the buttock region (n=805). Negative Pressure Wound Treatment (NPWT) was used in 22.1% of buttock wounds. Associated perineal injuries involved surgery to the male genitalia in 5% of cases (n=545 of 10,891) and 0.4% of operations on casualties underwent orchiectomy (n=44 of 10,891).

We highlight significant differences between the results of our study and the proposed NATO curriculum for surgeons, as well as previous classifications of surgical procedures in conflict.

Conclusions:

We show the surgery most frequently used to save life, eyesight and limb in the Afghanistan armed conflict. We highlight the most frequently operated on body regions and itemise the surgical procedures performed in war. Future armed conflict might change, but required surgical skills may not. We recognise that one surgeon cannot do it all, but we hope the present study's new anatomical categorisation of surgery provides the necessary supporting evidence for developing a more generalist approach to surgical training in preparation for future conflicts.

Introduction

Significant Government effort is expended during times of armed conflict to reduce the death rate from combat wounds of armed forces personnel. Data driven efforts using the Joint Theatre Trauma Registry) (JTTR) have improved body armour Personal Protective Equipment (PPE), and the analysis of wounding patterns have improved Combat Casualty Care (Eastridge, 2006).

Wearing body armour alters the way that energy is coupled to the body and therefore protects certain areas of the body better than others from fragmentation injury (Champion et al., 2010). Areas not protected by body armour show an increasing frequency of injury and various work has been carried out into the effect that body armour, a form of PPE, has had on the distribution of survivable wounds throughout the conflict in Afghanistan (Holcomb, 2007; Tai et al., 2008). The predominant wounding mechanism in Afghanistan was from "explosions" primarily caused by Improvised Explosive Devices (IED) (along with landmines, mortar or shrapnel, and grenades) (Owens, 2008).

Weapons technology continues to develop in efficiency and destructive force; ranging from antipersonnel mines and their fragments that maim civilians and combatants alike, to the indiscriminate devastation caused by the IED or suicide bomber (Coupland, 1999). As the enemy develops more effective weapons and adapts the type of conflict being fought, the injuries inflicted also change. Surgical intervention must adapt and improve in order to keep pace with these changes.

The focus of the present study is not on wounding patterns, but rather the impact of the multiplicity of wounding on the surgical interventions performed. Consolidating the surgical procedures of the most recent modern conflict will help prepare surgical practice in future armed conflicts and terror attacks.

The surgical case demographic breakdown for future conflicts is likely still to include combatants, humanitarian (CIV adults and PAEDS) and DNBI cases as outlined in Chapters 4 and 5. Other surgical considerations for future armed conflicts include combat operations where air superiority is absent. This may mean that fewer surgeons find themselves further forward in austere environments, resulting in potentially exaggerated timelines for Combat Casualty Care (CCC), and with limited equipment. As a result, surgeons may find themselves having to carry out the full complement of surgical procedures for conflict on their own (Hoencamp et al., 2014; Schwab, 2015).

Previous work in this area categorised surgical procedures by traditional surgical specialties and the skills traditionally attributed to them (Chapter 4). Blast injuries however, do not obey traditional surgical boundaries and requires a new approach. First, we categorised procedures by body region, and not specialties, and second, by doing so, we were able to account for the impact of the multiplicity of wounding caused by blast on surgical workload. Furthermore, because the raw procedure number was accounted for, the actual surgical skill set and workload was revealed. As such, this approach provides for the first time, the objective evidence-base required for future surgical curricula and planning.

The present study will build on studies that have gone before and shift the focus away from surgical specialty analysis which precedes this work (Maitland et al., 2016), and instead aims to present a new anatomical approach to surgery in armed conflict. Whereas in the past surgical procedures were recorded as occurring once per case (operation) despite, in some instances, being performed on multiple regions per casualty (e.g. multiple amputation), we instead aim to categorise the surgical procedures by anatomical region first, and then amalgamate into the most appropriate surgical specialty (Maitland et al., 2016; Jacobs et al., 2011; Ramasamy et al., 2010; Jacobs et al., 2012). Therefore, we hope to present a comprehensive account of surgical procedures aimed at managing the polytrauma nature of casualties wounded by explosions, and to present the complete analysis of surgical procedures from Afghanistan 2009-2014.

We will highlight which regions of the body were most frequently injured and surgically managed, as well as what the most frequent surgical procedures performed in each anatomical region were. The results will elucidate the surgical workload, and enable a comparison to previous studies, including a discussion around developing a standardised NATO curriculum (Hoencamp et al., 2014; NATO COMEDS; Hoencamp, 2016).

Since there is little international consensus on what the surgical procedures for armed conflict should be (Schwab, 2015), we hope that the present study may provide evidence to help to standarise the surgical procedures in order to save “eyes, life, and limb” in future conflicts and to improve surgical readiness for terror attacks.

Methods

Study design

An analysis of operating theatre records logged between November 5, 2009, and September 21, 2014 was performed. The total surgical cases (n=10,891) performed in the latter half of the conflict in Afghanistan until 2014 (the end of UK formal operations in Afghanistan at Role 3 Camp Bastion Facility) were analysed. The dataset consists of the digitised surgical procedures, and deaths, transcribed from handwritten surgical log-books, and imparted into Excel (Microsoft corporation) for analysis.

The combat activity, wounding patterns, surgeons, and mission emphasis of the hospital all changed throughout the years of the conflict studied.

Data collection

The methodology differed to previous studies (Chapters 4, 5) as instead of procedures being recorded once per case, we were able to account for procedures on multiple body regions that occurred on individual cases (e.g. amputation of multiple limbs per case) (Ramasamy et al., 2010; Jacobs et al., 2012). Anatomical regions operated on were used as a proxy to assess wounding patterns.

The present study goes into more depth than Chapter 1, and includes the anatomical region(s) operated on, and the type of surgical procedure used. Further analysis reveals the most frequently used surgical procedures for each anatomical region.

Mechanism of Injury

All surgical cases were analysed, and all injuries sustained by casualties including Disease Non-Battle Injury (DNBI) cases, were included.

Operation type

Cases, or operations, were categorised into primary (first-look) and secondary (take-back) surgery as in previous chapters. Primary and secondary surgical cases were included in the present study analysis.

Demographics

The present analysis is not broken down by casualty nationality – this is the comprehensive analysis of all surgical cases – all nationalities were included in the present study.

Anatomical regions

There was a total of 20,266 surgical procedures identified. Since a high proportion of the surgical procedures that took place in secondary operations (cases) did not document the body region on which they were performed, such procedures were excluded from the categorisation of surgical procedures by anatomical region. Once anatomical region was determined surgical procedures were classified by surgical specialty.

The analysis carried out is a detailed categorisation of the surgical procedures into anatomical regions on which they were performed.

Anatomical region categories were selected for their frequency of surgical intervention and the surgical procedures themselves were ranked according to the frequency they occurred.

To enable delineation between areas of the body most crucial to survival, we describe the surgical procedures to save eyes, life (areas of non-compressible haemorrhage), and limb, before making any further anatomical regional breakdown. This categorisation by anatomical region highlights not only the most important surgical skills performed, but also, the less vital procedures which occurred. In this way, we provide the evidence base for recommendations aimed at prioritising which procedures should best be carried out before, and which should be carried out after, soldiers are re-patriated.

The following subcategories were used to quickly group body regions to first outline the surgical procedures used (see Fig.1):

- **EYES:** Eye surgery was evaluated separately to head and neck surgery. Procedures on the eye were calculated once per case however there were multiple procedures on the eyes per case in some instances.
- **LIFE:** Non-compressible haemorrhage:
    - Junctional zones of haemorrhage: Neck; Groin and Axilla
    - Proximal vascular control procedures: chest cavity and abdominal cavity

- **LIMB:** Surgical procedures to the Upper Extremities (UE) or Lower Extremities (LE) were categorised into:
    - Upper Limb (UL) or extremity
    - Lower Limb (LL) or extremity

Further to this we analysed in more detail the surgical procedures performed, and by the following anatomical regions:

NERVES:

Regional analysis of nerves also included some anaesthetic procedures such as blocks and catheters that were not directly linked to nerve injury, but they were included in the analysis so that we could ascertain which nerves in what region of the body were most frequently operated on.

VESSELS:

Regional analysis of major vasculature was carried out and subcategorised into regions of:

- non-compressible haemorrhage: groin, neck and axilla and abdominal cavity and chest cavity
- compressible haemorrhage: extremity trauma (upper limb and lower limb)

HEAD and NECK (including face):

- Neurological (skull; spine; brain)
- Head
- Orbit
- Neck
- Trachea
- Maxilla
- Mandible

- Face
- oral cavity
- nose; ear/pinna
- scalp

VISCERA:

The chest and abdominal cavities were analysed as follows:

1. Chest region: chest cavity; chest wall; diaphragm; heart and lungs; oesophagus
   A. Thoracic procedures
   B. Regional analysis
      - chest cavity
      - chest wall
      - lungs
      - diaphragm
      - oesophagus
      - heart
2. Abdomen Region: abdominal cavity; and abdominal wall
   A. Abdominal wall procedures
   B. Surgical treatment of open abdomens
   I. To carry out this analysis the laparotomy procedures were divided into:

      - a. Damage Control (DC) laparotomies and

      - b. Secondary laparotomies

   The following procedures were considered respectively for each laparotomy:

   i. Non-closure techniques [Negative Pressure Wound Treatment (NPWT); partial/temporary closure techniques e.g. internal closure; flap, mesh; packing]
   ii. Delayed Primary Closure (DPC)

Cases that did not document any closure procedure were recorded as abdomens not closed.

C. Regional analysis:

Abdominal cavity procedures carried out during laparotomy:

Intestine:

large intestine; small intestine; stoma formation; peritoneal procedures; omentum procedures)

Spleen

Liver

Pancreas

Stomach

Kidneys

Percutaneous Endoscopic Gastrostomy (PEG) tube and Naso-Gastric (NG) tube insertion (where documented)

PERINEUM:

The perineum and ano-rectal region included: buttocks; rectum; anus; peri-rectal and anorectal regions.

- a. Urogenital: penis; urethra; scrotum (penile; scrotal; urological procedures on male genitalia)
- b. Buttock [gluteal muscle including Penetrating Gluteal Injuries (PGI)] and anorectal region

Thereafter, Upper Extremity and Lower Extremity were categorised into an overarching musculoskeletal (MSK) region enabling a more detailed analysis:

MUSCULOSKELETAL:

I. Lower Extremity/Limb:

A. Knee: Popliteal fossa; knee; patella and patella ligament

B. Foot:

i. Toe

ii. Calcaneus

iii. Talonavicular joint

iv. Hindfoot

v. Medial malleolus

vi. Midfoot

vii. Achilles

viii. Metatarsophalangeal Joint (MTPJ)

C. Leg: tibia; fibula; tibial plateau; calf

D. Ankle

E. Hip: femur; hip; sub-trochanteric

II. Upper Extremity/Limb (hand also subdivided and analysed separately)

a. Shoulder

b. Scapula

c. Radius

d. Ulnar

e. Clavicle

f. Humerus

g. Wrist

h. Elbow

III. Hand: nail; finger; tendon

IV. Fascia

V. Pelvis; sacrum

VI. Torso-Wall and Flank: incl. posterior chest wall (back) and excluding buttocks.

Surgical specialism

The results of this anatomical analysis were amalgamated into the surgical specialisms which traditionally covered the anatomical regions above.

Not all of the 20,266 surgical procedures fell into the anatomical regions outlined in this study. This was because an anatomical region was not always provided for the surgical procedure carried out. This typically occurred when the surgeon was performing debridement, or wound closure, and especially for secondary cases. Therefore, these procedures were excluded from this study. As stated before, certain other procedures on various anatomical regions were not included in the study as they occurred at such low numbers.

In the end, 13,909 procedures were categorised and allocated to the following surgical specialties:

Maxillofacial surgery: Head and neck [(excluding vascular, neurological; eyes and face (see plastics)]; the hard and soft tissues of the oral (mouth); maxillofacial region: oral cavity; maxilla, mandible, orbit

Obstetrics and Gynaecology: medical and surgical specialty encompassing obstetrics (pregnancy, childbirth, and the postpartum period) and gynecology (female reproductive system).

Vascular – Arteries and Veins and major vessels to the extremities, chest, abdomen including proximal vascular control cases

Cardiothoracic – chest region: lung, heart, major vessels of the chest cavity; (some overlap with vascular above); anterior chest wall; diaphragm; chest cavity

Upper Gastro Intestinal (GI)- oesophagus, stomach, duodenum, pancreas and gallbladder, spleen

Colorectal – small and large intestine, rectal and anorectal perineum region, and buttock region

Hepatobiliary - liver, pancreatic, biliary and gall bladder (some overlap with Upper GI above).

Urology - kidneys, ureters, bladder, prostate and male reproductive organs (urethra and urogenital region).

Plastics - hand trauma and soft tissue injuries and perineum (buttock) and (Torso Wall; Flank); lower limb trauma (see orthoplastic); head and neck (excluding vascular; neurological; eyes; and face); ear reconstruction; facial reconstruction; burns (see also Chapter 5; paediatric surgery).

Orthopaedics – knee; hip(femur); pelvis; spine (including cervical spine surgery); foot and ankle; shoulder (clavicle; scapula); elbow; hand; wrist; humerus; radius and ulna.

Orthoplastic – from the total lower limb and upper limb trauma respectively, after orthopaedics specific regions and plastics were deducted, the remainder we consider as falling within the orthoplastic approach to lower limb and upper limb trauma and soft tissue injuries as is currently the standard (BOA & BAPRAS guidelines, 2010). Hand trauma was included in orthoplastic as typically it can be ortho/plastic.

Paediatric trauma cases (see also Chapter 5).

We also included a separate direct comparison to the breakdown of procedures by specialty (see Fig. 5, Table 2) using the classification from Ramasamy et al., 2010.

We also compare the findings of the present study to the recent discussion of the NATO curriculum (Hoencamp et al., 2014; NATO COMEDS) and highlight some key differences between our dataset and their proposed curriculum (see Table 1).

Statistical analysis

Statistical analyses were performed with the use of Excel Microsoft software, version 2016. Statistical analysis with the z-test was used to compare proportions of body regions, surgical procedures and surgical activity, with previous studies. Significance was accepted at the 5% level ($p<0.05$).

Results

The surgical cases were analysed further to establish the regions of the body where surgery was performed (Fig.1). These can roughly be broken down into: 3996 cases involving the right side of the body and 4110 to the left (Fig.1).

A case fatality rate of 96 deaths per 10,891 cases was evaluated by surgical procedure: 9.1% of cases that involved craniotomy/craniectomy procedures died (n=1 of 11).

Procedures categorised by body region are listed according to the frequency in which they were performed, the top 5-10 most frequently carried out procedures, or primary procedures by anatomical region.

For comparison of procedures to previous proposed surgical skill set for surgery see Table 4 and sub-itemisation below:

6.1. EYES, LIFE, LIMB:

Vascular procedures to junctional zones of non-compressible haemorrhage; eye procedures; and limb amputations are shown in Figure 1.

The breakdown of cases where amputation procedure was performed, and those carried out on the eyes and the junctional areas (axilla; groin; neck) that were vascular in nature i.e. to stop bleeding, are summarized in Figure 1 as follows:

- **6.1.a Eyes:**

Surgical intervention to the eyes was required in 3.8% of cases (n=414 of 10,891) (Fig.1). There were 414 eye procedures calculated once per case. However, there were multiple procedures on the eyes per case in some instances, and the primary eye surgical procedures can be broken down as follows (n=505): washout irrigation and EUA of the eye (n=263); debridements (n=123); repair globe eye lacerations and wounds (n=46); enucleation and evisceration procedures (n=44); canthotomies (n=29) (Fig.1).

- **6.1.b Life:**

Operations that involved proximal vascular control procedures were identified (n=360), some of which required multiple regions of vascular control. The junctional zones/non-compressible hemorrhage areas shown in Figure 1 reveal that there were significantly more groin proximal vascular control procedures 20.8% (n=75 of 360) than neck 7.2% (n=26 of 360) (carotid artery and vein, subclavian artery and vein), or axilla 6.4% (n=23 of 360) (axillary artery and veins) (20.8% vs. 7.2%; z=5.259; $p<0.001$) (20.8% vs. 6.4%; z=5.636; $p<0.001$).
Neck vascular procedures outlined in the present study were calculated as a subdivision of the overall head and neck procedures previously recorded (see chapter 1).

In total, 349 neck-related operations were carried out. Of these 169 were vascular neck related-procedures, including 26 to gain proximal vascular control (Fig.1). The primary vascular procedures listed in descending order were: neck dissection and exploration; ligation of internal jugular vein (and external jugular vein; and external carotid artery); vascular graft repair to the carotid artery.

There were 139 surgical procedures to the axilla junctional region, of which 23 were to gain proximal vascular control in this junctional area. Primary procedures of a vascular nature to the axilla in descending order: exploration of axillary vessels; ligation axillary vein and proximal control of axillary artery; repair of axillary artery with reverse saphenous vein graft (RSVG); debridement washout and exploration of wounds (Fig. 1).

Over a quarter of groin related procedures (26.7%) were to gain proximal vascular control (n=75 of 281) (Fig. 1).

Most groin procedures were vascular in nature and the primary procedures were, in descending order: exploration of femoral vessels; ligation of femoral vein and artery for haemorrhage control; vascular repair vein graft to femoral artery; exploration of groin wounds and packing and harvest of saphenous vein.

Proximal vascular control was required in 3.3% of surgical cases (proximal vascular control cases n=360 of the 10,891 cases) and 165 of these cases involved exploratory laparotomies for proximal control – or 45.8% of proximal control procedures involved opening the abdomen to control the bleeding while just 30% of total proximal control cases were in the chest cavity (n=108). Overall, 23% of proximal vascular control procedures were for high Above Knee Amputations (Fig. 1).

Surgeons were significantly more likely to open the abdomen 45.8% (n=165 of 360) to gain proximal vascular control compared to the chest (30.0%) (n=108 of 360) (45.8% vs. 30.0%; z=4.369; p<0.001) (Fig. 1).

- **6.1.c Limb:**

There were a total of 2142 amputation procedures including. the 1723 amputations mentioned in Chapter 4 as we accounted for multiple amputations per operation (case). These were analysed further to see amputations per body regions (Fig.1). Bilateral extremity amputations accounted for 522 cases, 1091 were lower extremity amputations, and 142 were upper extremity amputations (Fig.1). However, a significant number of cases did not document the amputation anatomical region (22%; 387).

Lower limb amputation 50.9% (n=1091 of 2142) was significantly greater than upper limb amputation 13.0% (n=142 of 2142) (50.9% vs. 13.0%; z=26.600; p<0.001) (Fig. 1).

Bilateral amputations accounted for 24.4% of amputation procedures (n=522 of 2142) (Fig. 1).

Amputation procedures were involved in 20% (n=2142 of 10,891) of all surgical cases over the recorded time period 2009-2014.

Further analysis of the surgery carried out per anatomical region in order to highlight the most frequent surgical procedures performed is presented below:

6.2 NERVES:

There were 120 nerve operations recorded by case.

Primary nerve related procedures were: exploration; repair; transposition; harvest; graft

Regional analysis:

Ulnar n=38

Finger: digital n=19

Median n=17

Radial n=13;

Sciatic n=8;

Sural n=7;

Posterior tibial nerve n=4

6.3 VESSELS:

There were 990 vascular procedures recorded by case. The primary vascular procedures overall were: ligation; harvest; exploration; graft; repair

Regional analysis:

Proximal vascular control procedures n=360: neck, axilla and groin vascular control procedures have been shown and several which occurred in these junctional zones (Fig.1).

Femoral Artery n=102: bypass; explore; repair; shunt; re-anastomosis; ligation

Saphenous vein n=100: harvested; reconstruction venoplasty procedures; shunt; ligation; repair; bypass; revascularisation; interposition and reversed interposition graft.

Iliac vessels n=66: control bleeding; ligation; repair; exploration

Popliteal vessels n=53: repair; exploration; graft; thrombectomy

Brachial artery n=48: repair; shunt; explore; thrombectomy; graft

Carotid n=28- repair; patch graft; exploration; ligation

Subclavian vessels n=25: vein graft, avulsion, repair, graft to, exposure.

Ulnar artery n=15: vein graft; repair; ligation; interposition graft

Aorta n=4: cross clamp; repair

Non-specific vessel n=40: control bleeding; cautery; harvest; exploration; ligation; repair

The remaining vessels operated on included: tibial artery anterior and posterior; carotid artery and vein as previously described; colic artery (n=2); brachial vein (n=1); lumbar veins (n=1); brachio-cephalic vein (n=6) and inferior vena cava (n=6)

Other procedures of note that were infrequent: internal jugular vein filter placement; embolectomy and arteriotomy.

6.4 HEAD and NECK incl. FACE:

Figure 1 depicts the breakdown of procedures on the eyes (n=414 procedures recorded once per case, n=505 total eye procedures), and the vascular procedures to the junctional neck region (n=169). There were 1253 head and neck procedures overall (not including those on the eyes). Further breakdown of the remaining procedures by region is as follows:

Regional analysis:

Neurological; n= 25:

- Craniectomy/otomy n=11: craniotomy and evacuation of hematoma (n=1), craniectomy of compressed open skull fracture, debridement of cranium, hemostasis following GSW to cranium (n=1). Of the procedures involving craniectomy or craniotomy 1 died of wounds – as this procedure was infrequent this is equivalent to a 9.1% case fatality rate for this procedure.
    - Using casualty nationality by proxy to compare the proportion of craniectomy/otomy procedures (n=11) in a population wearing a helmet (ISAF) 18.1% (n=2 of 11) vs. without (civilians) (n=6 of 11) 54.5% (demographic not documented n=3) (18.1% vs. 54.5%; z=-1.775; p=0.106).

- Skull n=13: excision of depressed skull fracture; fracture debridement; closure of open fracture skull; replacement of skull cap post craniectomy; exploration of fracture
- Remainder: spine procedures (n=4) such as fixing of Halo device; cervical spine (n=0)

Head n=130: procedures to the head: fragment removal, exploration of injuries, debridement of wounds, closure of lacerations, and repair of structures

Orbit n=21: explore; repair lacerations; periorbital abscess drainage; lavage/washout wounds

Neck n=349 excluding the vascular operations to the neck: were attributable to exploration (n=114) of wounds; debridement and washout of wounds; repair of structures and wound closure; removal of fragments and foreign bodies; drain placement (Fig. 1).

Trachea n=125: There were 101 tracheostomy procedures; the remainder were injuries to the trachea: repair of trachea, debridement of injury, closure of trachea.

Mandible n=41: Open Reduction Internal Fixation; debride fracture; repair fracture; wiring of mandible/teeth; reconstruction mandible; washout of mandible; relocation dislocation; removal of foreign body (fragmentation/bullet).

Maxilla sinus n=34: debridement wounds; reconstruction maxilla; fracture exploration and washout; stabilisation fracture

Face: 5.2% of cases involved surgical procedure to the face (n=564): repair facial lacerations; debridement of burns to face; removal of foreign bodies/fragmentation

- Lip debridement n=71
- Ear/pinna n=65: debridement; repair laceration; repair avulsed ear; DPC; reattachment; reconstruction

- Cheek n=53: Delayed Primary Closure (DPC); excision of wound; abscess; exploration; debridement
- Nose n=41: Manipulation Under Anaesthesia (MUA) of nasal bone fracture; washout; suture lacerations; reconstruction
-

Oral cavity n=49:

- Tongue/mouth: repair of lacerations
- Teeth tooth n=18: extraction; suture gums; salvage of teeth; removal of broken teeth.
- Tonsils: abscess drainage; tonsillectomy

Scalp: - n=132: exploration and debridement of scalp wounds; repair suture; partial reconstruction of wounds

Burns: n=227 (see Chapter 5 for further details).

6.5 VISCERA:

The chest and abdominal cavities were analysed as follows:

1. **Chest region: chest cavity; lungs; diaphragm; heart and anterior chest wall (n=956)**

   Overall, 8.8% of cases involved thoracic procedures (total procedures to the chest region n = 956). There were a total of 260 thoracotomy and sternotomy procedures. Other types of thoracotomy procedure, where documented, included: clamshell (n=25); anterolateral thoracotomies (n=2); pericardial window (n=10); thoracostomy (n=5). We also included chest drain insertion (n=274) in this category.

   There was no significant difference in thoracotomy procedures between the present study [thoracotomy procedures (incl. sternotomy etc. above) 1.3% (260/20,266)] when compared to Ramasamy et al., (2010) [1.4% (31/2210)] (1.3% vs. 1.4%; z=0.393; p=0.695).

   A. Thoracic procedures

   Primary thoracic procedures: Thoracotomy exploration of chest cavity; chest drain insertion; debridement of multifragmenting wounds; resection of lung and repair of lacerations to lung; repair diaphragm lacerations.

B. Regional analysis

Chest cavity n=718: Thoracotomy (see above); chest drains (see above); DPC/closure of chest; packing of chest cavity; debridement of multiple fragment wounds and removal of foreign bodies

Chest wall n=73: procedures: DPC; evacuation of hematoma; closure of wounds; reconstruction of wall/SSG; Incision and drainage of abscesses; Change Of Dressings (COD)

Lungs n=70: pneumonectomy (n=4); repair of lacerations to lung; resection of lung (partial, non-segmental, wedge) (n=12); lobectomy (n=13); oversew lung; packing lung injuries; haemothorax and pneumothoraces
Tractotomy n=2

Diaphragm n=64: repair; laceration repair; oversewing of diaphragm; traumatic herniation repair

Oesophagus n=7: repair

- Heart n=31: repair of atrium, ventricles, pericardium; explore pericardium; closure of wounds to pericardium; pericardial window; decompression tamponade
-

2. Abdomen Region: abdominal cavity; and abdominal wall (n=3499)

Surgical intervention to the abdominal region involved 32% of cases (Abdomen: abdominal cavity and abdominal wall: total procedures to the abdomen region: n=3499 of 10,891).

A. Abdominal wall procedures

There were 343 surgical procedures on the abdominal wall itself which ranged from: closure/Delayed Primary Closure (DPC) of wounds; wound debridement and foreign body removal (shrapnel excision; fragmentation; bullets); Change of Dressings (COD). Abdominal wall wounds were managed by NPWT in 41.4% of cases (n=142 of 343).

B. Surgical treatment of open abdomens

I. To carry out this analysis the laparotomy procedures (n=1624) were divided into primary Damage Control (DC) laparotomies (n=999) and secondary laparotomies (n=625).

- **a. Damage Control Laparotomies:**

i. Non-closure techniques:

NPWT: 22.7% (n=277 of 999)

Partial/temporary closure techniques: 2.8% (n=28 of 999)

ii. Delayed Primary Closure (DPC) (n=11)

Total number of abdomens not closed: n= 733

- **b. Secondary Laparotomies:**

i. Non-closure techniques:

NPWT: 40.6% (n=254 of 625)

Partial/temporary closure techniques 19.7% (n=123 of 625)

- Internal closure/closure of midline fascial layer
- Flap/mesh/Split-Skin-Graft SSG
- Packing: propax; celox; gauze

ii. Delayed Primary Closure (DPC) n=63

Total number of abdomens not closed: n=185.

Total laparotomy cases where abdomens were not closed was 56.4% (n=918 out of total n=1624).

Total laparotomy cases where abdomens were temporarily closed was 42.1% (n=682 out of total 1624).

Abdominal cavity procedures carried out during laparotomy (n=1624) were analysed as follows:

C. Regional analysis:

Intestine (n=1137): Of the total 10,891 surgical cases 10.4% involved intestinal procedures (some regions were not documented):

- Large intestine n=421: anastomosis (colo-colonic); resection; diversion; closure of mesentry; EUA; division of colon; stapling; splenic flexure mobilisation or repair
    - Colonic perforation: n=3
- Small intestine n=273: oversew; resection; removal bullet/fragments (foreign body); repair; anastomosis (duodenojejunostomy) ; decompression of bowel
    - Duodenum procedures n=4: repair; stapling
- Stoma formation n=180: colostomy most frequently (n=128).
- Peritoneal procedures n=71: exploration retroperitoneal space, evacuation of hematoma, haemorrhage control, closure, packing, removal of fragmentation, drainage, lavage
- Omentum procedures n=10: omental plug to liver; excision; omentectomy; omental flap reconstruction; patch repair

Significantly more surgery was carried out to the large intestine 37.0% (n=421 of 1137) than the small intestine 24.1% (n=273 of 1137) (37% vs. 24.1%; z=6.677; $p<0.001$).

Spleen n= 116: splenectomy

Liver n=59: packing; oversew; repair; resection; drainage; lobectomy

- Liver lacertation: n=15

Pancreas n=48: drainage of pancreas; haemostasis; exploration; removal of tail/distal pancreatectomy; subtotal pancreatectomy; pancreatectomy

- Pancreatic drainage: n=3

Stomach n=45: repair lacerations; resection; debride; closure of wounds/holes; oversew

Kidneys n=39: repair lacerations; nephrectomy: n=26; closure of capsule; exploration; packing; frag removal; 4 adrenalectomies; cautery of renal bed bleeding

Intestinal anastomotic leak n=3

Percutaneous Endoscopic Gastrostomy (PEG) tube n= 158; Naso-gastric tube (NG): n=27

Biliary; Gallbladder procedures n=0

6.6 PERINEUM:

6.6.a Urogenital:

Primary penile; scrotal and urological procedures on the male genitalia (Fig. 2).

Overall 5% of surgical cases (n=545 of 10,891) involved surgery to the male genitalia, despite this, just 0.4% (n=44 of 10,891) involved orchidectomy.

There were 376 surgical procedures on the scrotum (Fig.2).

The top 5 surgical procedures on the scrotum were: debridement and scrotal exploration; repair; orchidectomy; excision of wounds and reconstruction procedures e.g. tunica vaginalis.

There were 143 procedures on the penis (n=127); male urethra (n=8) and ureter (n=8: anastomosis; segmentation; stent; repair; ureterectomy) (Fig.2).

Primary penile procedures: ureter and urethral procedures; closure of lacerations to penis; repair of penile structures; exploration debridement and washout; excision of wounds; reconstruction.

Primary urological procedures: stenting; repair; ureteric diversion/junction, ureterectomy; reconstruction (Fig.2).

Considered separately, the primary bladder procedures (n=26) were: repair and oversewing of the bladder (n=17); exploration; irrigation; reconstruction; cystectomy. In addition, there were: cystourethrogram procedures and 3 labial procedures and 81 catheterisation procedures incl. suprapubic (n=33).

6.6.b. Buttock and Anorectal region:

Primary procedures to the buttock, and anorectal region (n=919), or, 8.4% of operations, involved surgical procedures to the buttock and/or anorectal region (n=919 of 10,891).

The buttock (n=805) and anorectal region (n=114) taken to include the buttocks; rectum; anus; perirectal and anorectal region was involved in 1 in 13.5 cases and is broken down as follows:

Primary procedures buttock/gluteal region: debridement washout of wounds; exploration haemostasis of buttock wounds; packing of multi-fragment wounds; closure techniques incl. Delayed-Primary Closure (DPC), Change of Dressing (COD).

Negative Pressure Wound Treatment (NPWT), was used in 22.1% of buttock wounds (n=178 of 805).

Primary anorectal procedures: Exploration Under Anaesthesia (EUA) rectum; rectal washout incl. debridement of rectal injury e.g. pararectal degloving; stapling, excision and division of rectum; Packing and DPC procedures, removal of foreign body (fragmentation), perianal abscess incision and drainage (n=52).

In the present study 1% of surgical cases required further endoscopic investigation of wounds to the perineum: buttock/anorectal regions (Fig.2) n=92) endoscopic procedures: sigmoidoscopy; proctoscopy procedures.

22.4% of all casualties received NPWT (n= 2444 of 10,891).

We show 1 death from buttock GSW, 1% of case fatalities (n=1 of 96).

6.7. MUSCULOSKELETAL:

Figure 1 shows the number of amputations by extremity (Upper Extremity UE; Lower extremity LE). There were 2.0 amputation procedures per 10 cases (n=2142 of 10,891). There were significantly more lower extremity amputations 50.9% (n=1091 of 2142) than upper limb amputations 13.0% (n=142 of 2142) (50.9% vs. 13.0%; $z=26.600$; $p<0.001$) (Fig. 1).

The majority of procedures carried out on extremities were: COD; DPC; Debridement and washout of wounds; amputations and application of external fixators (external fixator).

There were 1051 applications of external fixators and 108 skeletal traction pins.

There were 101 Open Reduction Internal Fixation using k-wires.

However, compared to previous similar studies, the rate of external fixation was higher 5.1% (n=1051 of 20,266) compared to Ramasamy et al., (2010) 2.9% (5.1% vs. 2.9%; z=4.557; $p<0.001$) (Fig 1).

There were 497 fasciotomies: lower limb n=271; upper limb n=117

There were 1931 debridement procedures to the extremities.

There were 59 fracture reductions to the extremities.

I. Lower Limb/Extremity:

There were 2174 surgical procedures on the leg.

Primary Lower Limb (LL) related procedures were: amputation (primary amputations (n=982); debridement and washout of wounds; removal of foreign bodies (bullets/fragmentation), application of external fixator; DPC and COD (Fig. 1).

Regional analysis:

A. Knee: n=476

- Popliteal fossa n=9: exploration and debridement; nerve block; popliteal vessels (see Vessels)
- Knee n=467: washout and debridement; amputation; DPC; arthrotomy; exploration; pop; Incision and drainage of joint
  - Patella and patella ligament n=12

B. Foot: n=546

- Foot n=400 (foot documented but no further regionalisation recorded)

i. Toe n=52

ii. Calcaneus/heel n=42 including: debridement; exploration; calcaneus cuboid dislocation; Delayed Primary Closure (DPC) wounds and debridement of wounds

iii. Talonavicular joint n=3: fracture dislocation stabilisation

Talus n=6

Cuboid n=1

Subtalar n=2: dislocations

iv. Hindfoot n=1

v. Medial malleolus n=2

vi. Mid foot/ mid-foot n=18

vii. Achilles tendon n=6

viii. MTPJ (Metatarsophalangeal Joint) n=4

C. Leg: n=497

Shin/tibia n=267

Fibula n=37

Open fractures n=48

Tibial plateau n=3

Calf/calves n=190

D. Ankle: n=199

- Through ankle amputation n=8

E. Hip: n=336

Femur n=177

- o Femoral external fixator n=14

- Hip n=158: washout closure DPC debridement of wounds to hip, donor site for grafts, removal of foreign body (fragmentation; bullet). Abscess drainage
- Sub-trochanteric n=1

Arthrotomy n=28: 20 to the knee and 8 to the ankle, femur, tibia

II. Upper Limb/Extremity:

There were 1962 surgical procedures on the arm (Fig. 1).

Primary surgical interventions on the arm were: amputation; removal of foreign body (fragmentation; bullet); washout and debridement and excision of wounds; EUA; COD

Regional Analysis:

a. Shoulder n=496: debridement; removal of foreign body (fragmentation/bullets); reduction of dislocation; Exploration Under Anaesthesia EUA; Change of Dressing COD; DPC

b. Scapula n=32: DPC; exploration; excision of wounds; fragmentation removal
c. Radius n=19
d. Ulna n=31
e. Clavicle/clavicular n=18: nerve catheter insertion, fracture stabilisation, removal of foreign body (fragmentation; bullet); clavicular excision
f. Humerus n=61
g. Wrist n=130: through wrist amputation n=3
h. Elbow n=231: fracture stabilisation e.g. external fixator/Plaster of Paris (POP); dislocation (MUA); debridement, washout and DPC of wounds, removal of foreign body; amputation

III. Hand:

There were 1227 hand operations recorded by case (Fig. 1).

Primary hand related procedures were: debridement and washout; exploration of wounds; repair of tendons and nerves; nail bed repair; reconstruction; finger terminalisation/amputation

Regional analysis:

Hand n=1091: location rarely specified but includes Palm: n=13; Distal Interphalangeal Joint (DIP): n=5; Proximal Interphalangeal Joint (PIP) n=13; Metacarpophalangeal joint (MCP) n=5

Finger n= 399: terminalisation/amputation debridement and washout; exploration; fingertip repair; reconstruction (flaps; SSG)

Nail n= 71: nail bed repair (n=22); avulsion repair; debridement and washout

Extensor tendon n=16: washout, exploration and repair

IV. Fascia:

There were 497 fasciotomies, the split between lower limb: n=271, to upper limb: n=117 (Fig. 1).

V. Pelvis; sacrum:

There were 146 surgical procedures on the pelvis (Fig. 1).

Primary surgical interventions on the pelvis region were: external fixator; proximal control; exploration; packing; debridement

Regional analysis:

- Pelvis n=122: external fixator (n=32); proximal control; exploration; packing; debridement
- Sacrum n=24: wound debridement; GSW exploration and partial sacretectomy

VII. Torso Wall and Flank:

There were 1427 surgical procedures on the torso wall (Fig. 1)

Primary surgical interventions on the arm were: debridement and washout of wounds; closure of wounds and DPC and excision of wounds; Split thickness Skin Graft SSG/reconstruction; removal of foreign body (fragmentation; bullet); abscess drainage

Regional analysis:

- Back n=597
- Flank n=211: debridement washout of wounds; closure of wounds; cod; drainage of abscess; DPC
- Pectoral/pectus n=2: debride, GSW

In Figure 4 we show how the amalgamated categorisation of surgical procedures by anatomical region translates into the traditional specialties. In Figure 5 we show differences to Ramasamy et al., (2010), and the breakdown of procedures by specialty.

A comparison to the possible NATO curriculum discussed by the Committee of Chiefs of Military Medical Services, COMEDS is outlined in Table 3.

A comparison of the present study findings to the surgical procedures suggested for the damage control surgical skill set by Hoencamp et al., (2014) is shown in Table 4.

Discussion

This is the third analysis of surgical procedures that were carried out in the conflict in Afghanistan 2009-2014.

In previous studies of preventable deaths in Afghanistan, approximately 40% were reported to originate from truncal trauma, and 20% from head injuries (Pannell, 2011; Neff, 2013). The present study found that there was a 9% case fatality rate in surgical cases where craniotomy/craniectomy was performed with no significant difference between casualties who wore a helmet and those who did not (CIV vs. ISAF vs. CIV). Of the 10,891 cases analysed, there was a case fatality rate of 0.9%, or 1 death per 113 cases. The main mechanism of injury was blast injury. This follows our previous study showing that blast injury accounted for the highest proportion of surgical cases (Maitland et al., 2016) (Chapter 1).

Explosive force distribution across the body around Personal Protective Equipment (PPE) may account for fragments and debris injuring vital structures at junctional areas of the body. This is perhaps because these areas, by necessity, remain unprotected to permit free body movement and, therefore, are more vulnerable to trauma. The nature of injuries to junctional zones of the body (axilla, groin and neck) is such that a tourniquet cannot be applied, and direct pressure is difficult to administer. These so-called "non-compressible regions" include the chest and abdomen. Significantly more surgical interventions on junctional zones of non-compressible haemorrhage were on the groin compared to the neck and axilla ($p<0.001$; 6.1.b; Fig.1; Fig.3;). We have previously shown that the neck suffered more trauma than the axilla and groin in the civilian (adult and paediatric) and ISAF groups (see Chapter 5), suggesting injuries in this region are still currently not preventable by PPE or body armour.

The shoulder is a close anatomical neighbour to the neck, and perhaps unsurprisingly we also show that injuries to the shoulder girdle accounted for 22.0% of surgical cases (6.7.II: n=496 of 10,891) or 25.2% of upper limb surgery (6.7.II: n=496 of 1962). The shoulder is also a region of non-compressible haemorrhage, and given almost a quarter of surgical cases involved procedures to this region, we suggest that injury to the shoulder region is currently not preventable by PPE, or body armour.

In conflict, people die primarily of haemorrhage - otherwise known as exsanguination (Pannell, 2011). Previous studies have shown that truncal haemorrhage (including thorax; abdomen and pelvis) accounts for most of the preventable deaths, as many of these would be non-compressible haemorrhage (Eastridge et al., 2012). The present study shows that there was a significant requirement for thoracic surgical interventions to the chest region (6.5.1.B: chest cavity; chest wall; diaphragm; heart and lungs) not previously analysed. We show a similar use of thoracotomy procedures compared to Ramasamy et al., (2010), however further breakdown of procedures in the chest region were not available for comparison. In our detailed analysis we found that 8.8% of cases involved thoracic procedures (6.5.1: n=956: chest cavity; wall, diaphragm, heart and lungs). Procedures to the chest region totalled 956 per 10,891 cases, or 1 thoracic procedure per 11.4 cases. Primary chest procedures overall were: Thoracotomy-exploration of chest cavity; chest drain insertion; debridement of multifragment penetrating chest wounds; resection of lung and repair of lacerations to lung and repair diaphragm.

The present study shows that the abdominal region (abdominal cavity; abdominal wall) accounted for 3499 surgical procedures and included the 1624 laparotomies mentioned in Chapter 4 (see 6.5.3). Chapters 4 and 5 highlighted the fact that 360 cases required proximal vascular control surgical procedures and 23% were associated with Above Knee Amputations (AKA). We show that surgeons were significantly more likely to open the abdomen to gain proximal vascular control compared to the chest cavity (see 6.1.b; Fig.1). The present study accounted for multiple regions operated on in each proximal vascular control case. We found that 45.8% of total proximal vascular control procedures involved opening the abdomen to gain control of non-compressible haemorrhage at distal junctional zones (groin), while just 30.0% of total proximal control cases were in the chest cavity (Fig.1). Surgeons, therefore, were significantly more likely to open the abdomen than the chest for haemorrhage control (see 6.1.b: $p<0.001$).

The Canadian surgical experience in Afghanistan (2006-2009) reported a low requirement for thoracic operations and most frequent operations were to soft tissue and extremities (Brisebois, 2011). Similarly, Owens et al., (2008) showed a decrease in thoracic wounds compared to previous conflicts (Bilski, 2003; Chan et al., 2012; Owens et al., 2008,). These differences perhaps result from changing patterns of war and/or improved body armour.

The finding that the majority of proximal vascular control procedures in cavities took place in the abdomen (6.1.b; Fig.1; $p<0.001$), and that bilateral lower limb amputation was more likely than unilateral lower limb trauma (Chapter 5), is reinforced by the fact that we also found that: significantly more amputations were carried out to the lower limbs compared to the upper limbs (6.7: $p<0.001$); 23% of proximal vascular control procedures were associated with Above Knee

Amputations; 24.4% of amputations were bilateral (6.1.c); and that a significant majority of junctional zone (non-compressible haemorrhage) procedures were to the groin (6.1.b; Fig.1; Fig.3; $p<0.001$). Our analysis highlights, therefore, the unique combination of surgical procedural skills that lower limb blast trauma requires of the surgical team: bilateral lower limb proximal (AKA) amputations with associated non-compressible haemorrhage to the groin and the use of proximal vascular control procedures in the abdomen.

For the first time we analyse the procedures carried out within the abdominal cavity and show that the most common intra-abdominal organ operated on was the intestine;10.4% of cases involved intestinal procedures (6.5.2.C: n=1137 of 10,891), and that significantly more surgery was carried out on the large bowel 37.0% (6.5.2.C: n=421 of 1137) than the small bowel 24.1% (6.5.2.C: n=273 of 1137) (6.5.2.C: 37% vs. 24.1%; $z=6.677$; $p<0.001$). The second most common organ to require surgical intervention was the spleen (n=116) and thirdly the liver (n=59) (see 6.5.2.C). The abdominal wall wounds used Negative Pressure Wound Treatment NPWT 41% of the time. In 40.6% of secondary laparotomies, NPWT was the main temporary closure technique (6.5.2.B.I.b: n=254 of 625). The total number of abdomens not closed was 56.4% (6.5.2.B: n=918 of n=1624). This shows that a significant number of abdominal Damage Control (DC) surgery was not closed and went on to require re-look laparotomies for secondary procedures such as removal of packing, and repair of anastomotic leaks. The impact of the high proportion of open abdomens may lead to surgical training in non-closure techniques and may be difficult to achieve in future conflicts that may be less well equipped and may occur in more austere environments.

There were 990 vascular procedures overall, or 1 in 11 cases that required vascular intervention (see 6.3). The top 5 vascular procedures carried out were: ligation of vessels; harvest of vessels; vascular exploration to control bleeding; grafts and repair procedures. The most commonly operated on vessels for Damage Control were: the femoral artery; popliteal vessels because of injury, and the saphenous vein for grafting purposes. We show the most common procedures and the vessels most likely to be operated on in conflict zone and therefore highlight the most important vascular skills.

We show that 9% of case fatalities underwent craniectomy and craniotomy procedures before they died. Owens (2008) showed a significant increase in head and neck wounds. Regarding head injuries, Dubose et al., 2011 found that military patients who suffered traumatic brain injury (TBI) had increased survival compared to civilians with TBI. Military patients were more likely to have invasive monitoring and neurosurgical intervention (Blackbourne et al., 2012). This fits with our previous findings that the civilian population had a significantly higher fatality rate compared to ISAF (perhaps due to their not wearing helmets or body armour), however we show no significant difference between casualty nationalities and suggest that because the procedure was so infrequent (6.4: n=11), the sample was too small to obtain any meaningful results.

The head and neck region (not including eyes) highlighted surgical interventions commonly occurred on the face (n=564); the trachea (n=125) (of which 101 were tracheostomies); the neck (n=349, including vascular procedures outlined above) and the scalp (n=132) (see 6.4). Other regions of the body exposed to injury include the face which was injured in one third of all UK injured servicemen (2005-2009) (Breeze et al., 2012). One study of the facial injuries of UK troops from 2003-2013 found that 41.6% of survivors required secondary facial surgery when they returned to the UK (Wordsworth et al., 2017). We found, however, that facial surgery was required in only 5.2% of surgical cases (see 6.4) – a substantial decrease from these previous studies. We do not have an explanation for this finding.

The current study showed that the top procedures to the facial region were: exploration of wounds GSW or fragmentation; debridement and washout of wounds; repair of structures and wound closure; removal of fragments and foreign bodies and the repair of facial lacerations.

Injuries to the face in previous studies included to the eyes that of dust and debris (Coupland, 1991; Owens, 2008); and lower jaw/mandibular fractures. There is currently no agreed method of describing the location of civilian or military penetrating facial wounds (Breeze et al., 2012). For example, a high frequency of mandibular fractures may be recorded as "lower third" injuries but this description bears no relation to the position of any overlying skin wounds (Breeze et al., 2012). The mandibular trauma seen in conflict is primarily blast injury and fractures differ to those seen in blunt trauma in civilian life (Breeze 2011). The present study found that the primary surgical procedures to the mandible were: Open Reduction Internal Fixation; fracture debridement; repair fracture e.g. wiring of the mandible; mandibular reconstruction; washout; relocation of dislocation and removal of foreign body (fragmentation; shrapnel; bullets) but only 39 cases involved these surgical interventions.

Other facial bony structures included the maxillary sinus (see 6.4: n=34) which required the following surgical interventions: debridement wounds; reconstruction maxilla; fracture exploration and washout and stabilisation of fracture. Nasal bone fractures were the most common bony injury (see 6.4: n=41) and the primary procedures to manage them were: Manipulation Under Anaesthesia (MUA) nasal bone fracture; washout; suture lacerations and reconstruction. In combat-induced maxillofacial fractures, maxillofacial surgeons who are not always currently deployed as part of the surgical team have shown colleagues how to perform Intermaxillary Fixation (IMF) as it was known to reduce pain during patient transfer (Breeze 2011).

The infectious complications of Damage Control (DC) orthopaedics in war trauma are greatest following internal fixation e.g. intra-medullary nailing with 40% fracture site infection at 414 days post operation (Mody et al., 2009). We show that the predominant fracture stabilisation in Afghanistan was by external fixator (6.7: n=1051); there were 108 skeletal traction pins, and 101 Open Reduction Internal Fixation procedures using k-wires. This rate of external fixation was significantly higher 5.1% (n=1051 of 20,266) compared to Ramasamy et al., (2010) 2.9% (see 6.7: 5.1% vs 2.9%; z=4.557; p<0.001). Unfortunately, the log-book data set used in the present study did not document long term infective complications.

We consider separately the surgical interventions to the eyes.

Another unique area of the body vulnerable to injury is to the buttock (gluteal region). Gluteal injuries are associated with injuries to pelvic abdominal organs, vessels and the rectum. However, currently, because a standard for triage and evaluation of gluteal injuries does not exist, this may lead to avoidable unnecessarily poor outcomes (DiGiacomo et al., 1994; Lesperance et al., 2008). Glasgow et al., (2012) reported military casualties with colon or rectal trauma had elevated mortality rates, and that interventions such as faecal diversion was less frequent in Afghanistan than in Iraq, but those that received a faecal diversion had lower mortality (Glasgow 2012).

Buttock wounds can cover a large body surface area, and have an increased risk of contamination with associated high morbidity post recovery. Buttock wounds also present complex reconstructive challenges. We show that Negative Pressure Wound Treatment (NPWT) was used in the management of 22.1% of buttock wounds. We show 1 death from buttock GSW, 1% of case fatalities (see 6.6.b: n=1 of 96). In total NPWT (n=2444) was used to surgically manage a range of complex wounds and as a temporary closure technique in 22.4% of surgical cases (n=10,891) carried out in Afghanistan (see 6.6.b).

The present study showed that there was a high burden of injury to the buttock and anorectal region (buttocks; rectum; anus; peri-rectal and anorectal region) (see 6.6.b; Fig. 2). There were 805 surgical interventions to the buttock region alone, which included the following top 5 surgical interventions: Debridement washout of wounds; exploration hemostasis of buttock wounds; packing of multi-fragment wounds; closure/Delayed-Primary Closure (DPC); and Change of Dressing (COD). An additional 114 procedures to the anorectal region included: Exploration Under Anaesthesia (EUA) rectum; rectal washout incl. debridement of rectal injury e.g. pararectal degloving; stapling, excision and division of rectum; Packing and DPC procedures; removal of foreign body (fragmentation) and perianal abscess incision and drainage (n=52) (6.6.b; Fig.2). A further 93 injuries to this region required sigmoidoscopy or proctoscopy to investigate limitations of damage to the rectum and colon respectively, equivalent to 1.1% of casualties undergoing endoscopy (6.6.b; Fig.2). In total, therefore, the buttock and anorectal region accounted for 1 in every 13.5 surgical cases (see 6.6.b: n=805 of 10,891).

We show, anatomically close male genitalia were operated on in 5% of the operations, accounting for 545 surgical interventions (see 6.6.a: Fig.2). Of these 375 were to the scrotum; 143 to the penis; 26 to the bladder and 0.4% of all surgical cases involved orchidectomy (see 6.6.a). The urogenital surgery carried out is relatively low when compared to the high levels of buttock and anorectal region surgery, accounting for 8.4% of operations (see 6.6.n; Fig. 2).

Future conflicts may not have the surgical provisions found in Afghanistan at Camp Bastion's Trauma Centre. This study has itemised the surgical procedures carried out from 2009-2014, and in so doing provides the much-needed evidence for the effective training of surgeons in surgical procedures required for future conflicts. The evaluation of all of the surgical procedures performed (20,266) and the new categorisation of surgical interventions by anatomical region, have enabled us to analyse the impact of the multiplicity of wounding seen in Afghanistan, and in terror-related incidents occurring today, on trauma surgery. We show the surgical procedures most frequently used to save life, eyesight and limb in war (Fig. 1, 4).

We show the amalgamated categorisation of surgical procedures by anatomical region into traditional specialties (Fig.4; Table 1). We also found significant differences in the surgical specialty workload analysis when compared to previous accounts (Ramasamy et al., 2010): significantly more general surgery; head and neck surgery and significantly less: orthopaedic surgery; neurosurgery and burns related surgery was carried out (Fig. 5; Table 2; $p<0.001$).

We recognise that one surgeon cannot be expected to have all the requisite skills, but we hope this study will enable the military and government to decide better what key skills are essential for any surgeon in future conflicts regardless of surgical background. We compared the results of the present study and highlighted differences to the recent discussion held by the Committee of Chiefs of Military Medical Services, COMEDS, on a possible NATO curriculum (Table 3). The discrepancies or gaps we highlight can help implement much needed standardisation for NATO surgeons, and inform civilian training practices by presenting the most frequent surgical procedures by body region to account for the polytrauma caused by explosions (Fig.4; Table 1; Table 3).

We compare the findings of the present study (Table 4) with the previously suggested surgical skill set for war (Hoencamp et al., 2014) to ascertain the evidence base for this proposal. We found that some of the procedures suggested occurred at very low rates, whilst others that we found to be a significant proportion of surgical workload were not represented at all (see Table 4). We suggest, therefore, that a full template for the surgical procedures required for conflict and terror attacks does not yet exist, and we aim to carry this work out in the next chapter.

The findings of the present study may be incorporated into the management of the emergency surgical patient within the civilian practice in order to deal with terrorist attacks, mass casualty events and or catastrophies in times of peace and war.

As previously stated, the present study is a retrospective analysis of the surgery carried out during the latter half of the conflict in Afghanistan. We know that kinetics varied on the ground, and injury patterns may have changed, however, given the large sample size, and consecutive nature of this surgical interventional database, we believe that any variation will be mitigated by this extensive and comprehensive catalogue of the surgical procedures performed.

Conclusion:

This is the first study of its kind, which sets out to comprehensively itemise, and categorise, the surgical interventions carried out in the most recent modern conflict. The approach to analysis by anatomical region enabled us to account for the polytrauma nature of injuries caused by blast/explosion in Afghanistan. The main findings of this study help to highlight the most frequently performed surgical procedures in armed conflict, as well as the specialist anatomical regions and procedures which are paramount to the reduction of preventable death. It is hoped that our study may result in a more generalist approach to trauma surgery and surgical training in conflict and as well as in peace-time terror attack preparedness planning.

Figures and Tables

Figure 1: Eyes; Life and Limb

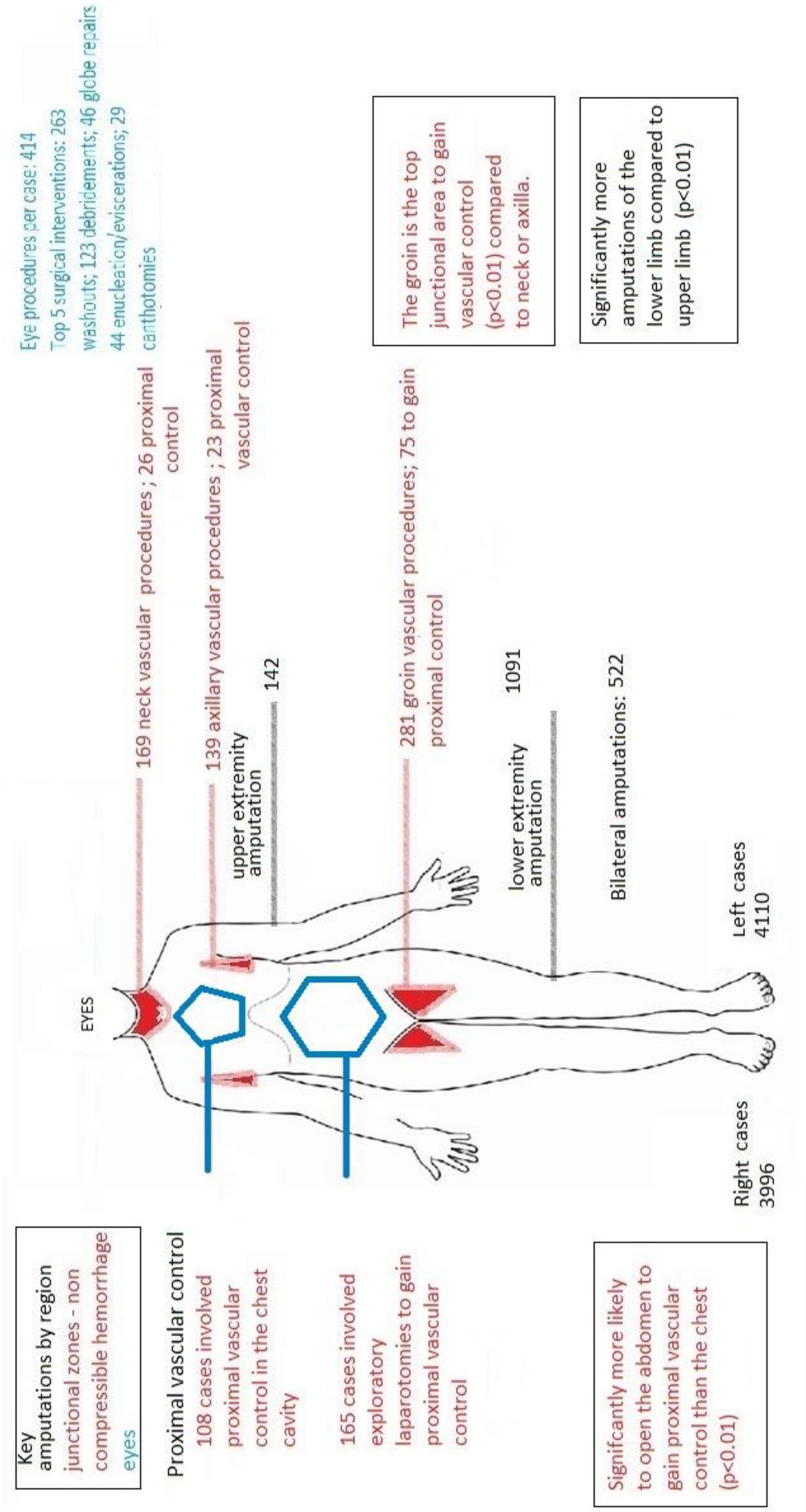


Fig. 1 Vascular procedures to junctional zones (outlined in red) of non-compressible haemorrhage (axilla, neck and groin); eye procedures; amputations and abdominal and chest cavity haemorrhage control (blue). Access areas opened in the chest and abdomen to gain proximal vascular control are indicated in blue

Figure 2: Top 5 genital, urological, buttock and anorectal surgical procedures

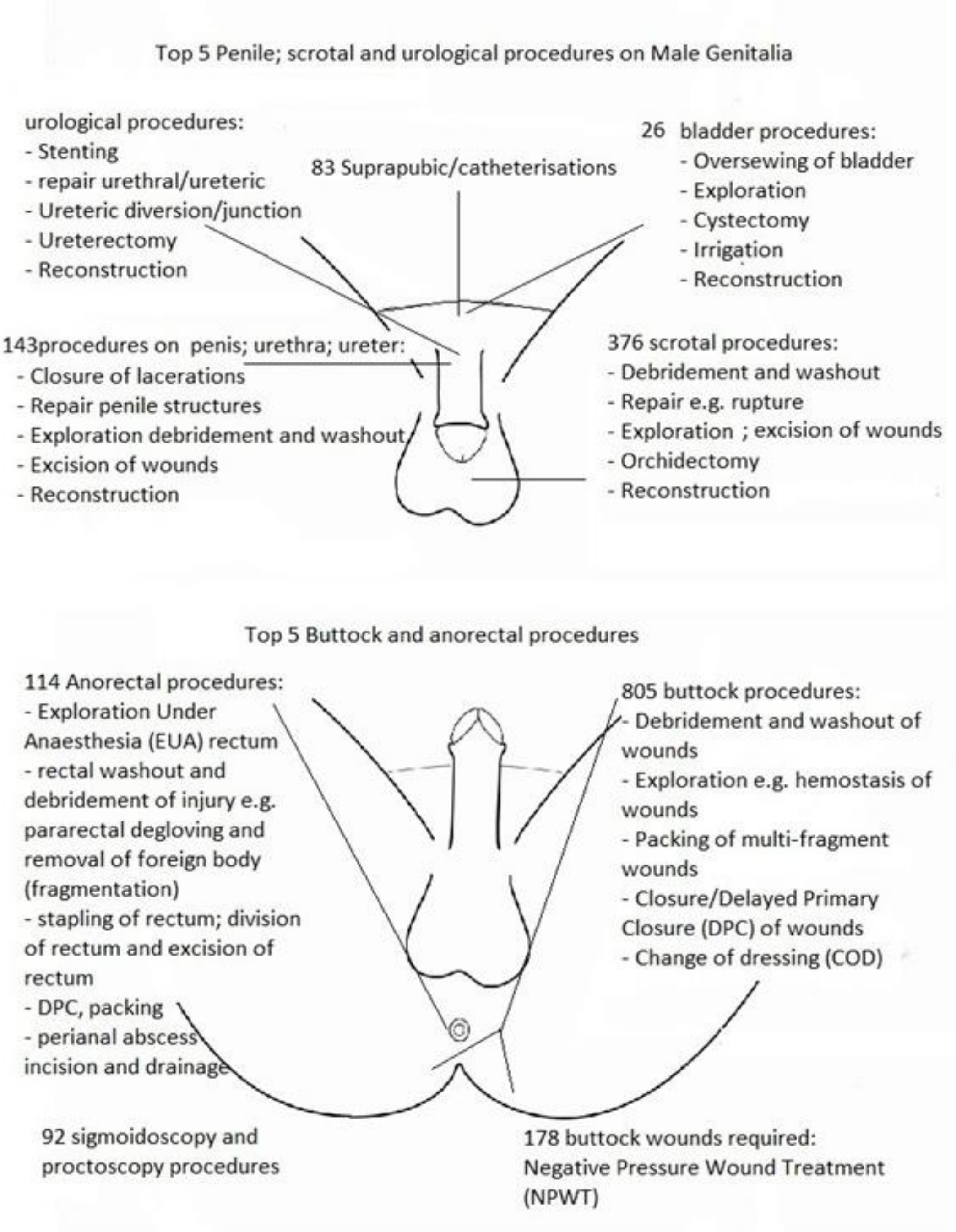


Fig. 2: Most frequent surgical procedures performed to the buttock, anorectal, and male urogenital regions (6.6a; 6.6b: surgical procedures to this region were performed in a total of 1464 cases). Tallies for regional procedures are shown on the diagram.

Figure 3: Most frequent surgical procedures to control non-compressible haemorrhage in junctional zones:

1. Groin	2. Neck	3. Axilla
Exploration of femoral vessels Ligation of femoral vein and artery Repair vascular vein graft procedures Exploration of groin wounds and packing; Harvest of saphenous vein	Neck dissection and exploration Ligation of vessels: i) internal jugular vein ii) external jugular vein iii) and external carotid artery Repair procedures: vascular graft repair to carotid artery	Exploration of axillary vessels Ligation axillary vein and proximal control axillary artery with reverse saphenous vein graft Debridement washout and exploration of wounds.
Significantly more proximal vascular control procedures were to the groin 20.8% (n=75 of 360) compared to the neck 7.2% (n=26 of 360) (carotid artery and vein, subclavian artery and vein) or axilla 6.4% (: n=23 of 360) (axillary artery and veins) (20.8% vs. 7.2%; z=5.259; p<0.001) (20.8% vs. 6.4%; z=5.636; p<0.001).		

Figure 4. Anatomical Categorisation of Surgical Procedures by Specialty

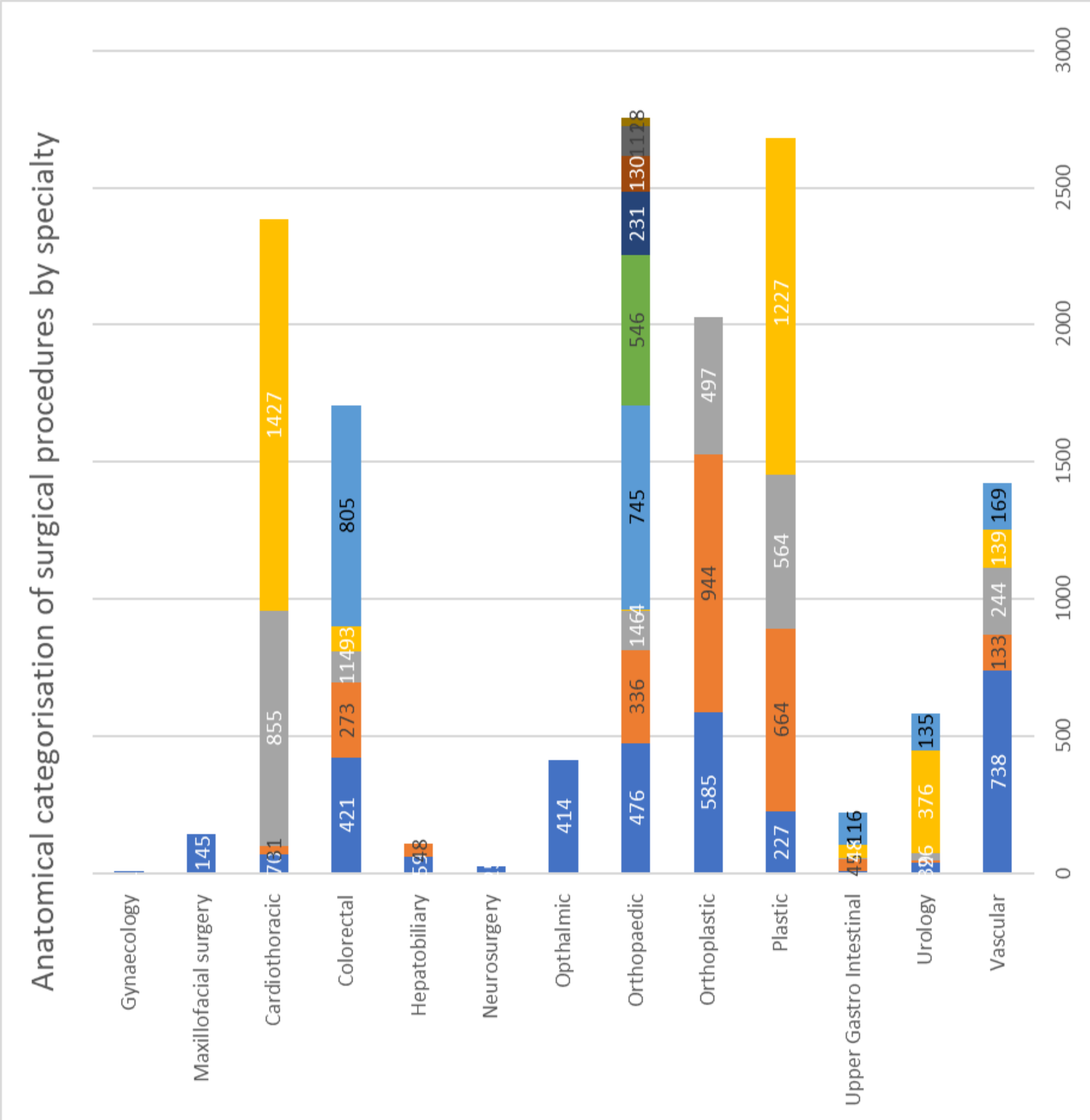
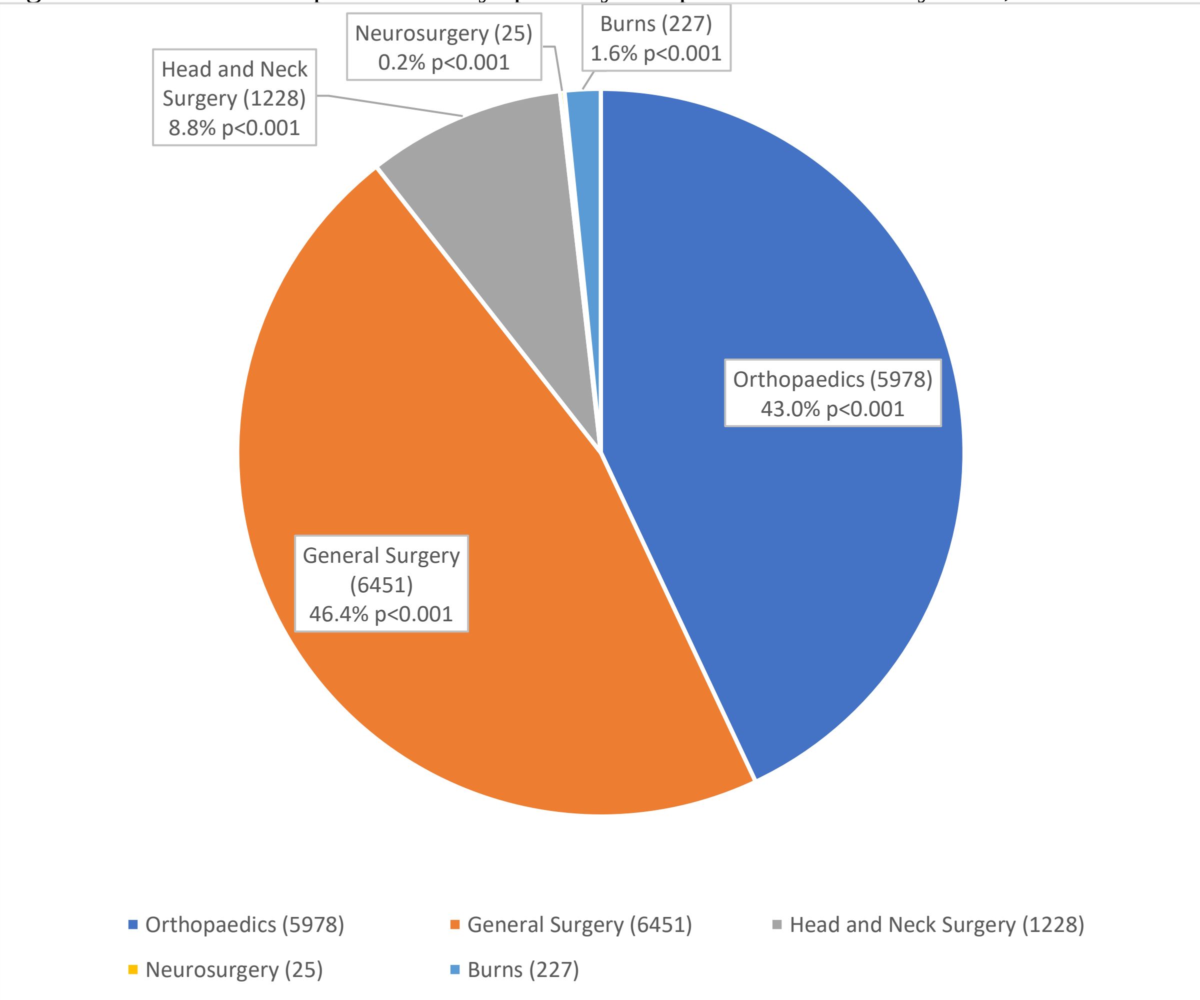


Fig.4 Anatomical categorisation of surgical procedures by specialty. The key for the histogram is shown below in Table 1a.

Table 1a – key to the histogram shown in Fig. 4

Maxillofacial	145									
Obstetrics and Gynaecology	10									
Cardiothoracic	Lung	Heart	Chest region: chest cavity; diaphragm; anterior chest wall	Torso wall (posterior chest wall (back); flank (excluding buttocks).						
	70	31	855	1427						
Colorectal	Small intestine	Large intestine	Ano-rectal	Sigmoidoscopy and proctoscopy	Buttocks					
	421	273	114	93	805					
Hepatobiliary	Liver	Pancreas	Biliary and Gallbladder							
	59	48	0							
Neurosurgery	25									
Opthalmic	414									
Orthopaedic	Knee	Hip and femur	Pelvis	Spine	Foot and ankle	Shoulder, scapula and clavicle	Elbow	Wrist	Radius; ulnar and humerus	Arthrotomy
	476	336	146	4	745	546	231	130	111	28
Orthoplastic	Lower extremity trauma and soft-tissue injury	Upper Extremity trauma and soft-tissue injury	Fasciotomies (upper extremity and lower extremity)							
	585	944	497							
Plastic	Burns	Head and neck (excl. eyes, face, vascular, neurosurgery)	Face and Ear	Hand						
	227	664	564	1227						
Upper Gastro Intestinal	Oesphagus	Stomach	Duodenum	Pancreas	Spleen					
	7	45	4	48	116					
Urology	Kidneys	Ureters	Bladder	Scrotum	Penis; urethra					
	39	8	26	376	135					
Vascular	Major vessels Extremities (incl. groin)	Chest Vascular Control	Abdominal Vascular control	Axillary vascular control	Neck and carotids					
	738	133	244	139	169					

Figure 5: Breakdown of procedures by specialty compared to Ramasamy et al., 2010.



See Table 2 for detailed analysis below.

Table 2: Comparison of breakdown of procedures by specialty to Ramasamy et al., 2010

	Breakdown of procedures by Specialty	Total procedures n=13,909*	Breakdown of procedures by specialty (Ramasamy et al., 2010)	Total procedures (n=2210; Ramasamy et al., 2010)	z-value	p-value
Orthopaedics	5978	43.0%	1463	66.2%	-20.322	p<0.001
General surgery	6451	46.4%	465	21.0%	-22.410	p<0.001
Head and Neck surgery	1228	8.8%	139	6.3%	3.924	p<0.001
Neurosurgery	25	0.2%	39	1.8%	-10.812	p<0.001
Burns	227	1.6%	104	4.7%	-9.611	p<0.001

Table 3

Comparison to the possible NATO curriculum discussed by the Committee of Chiefs of Military Medical Services, COMEDS 2014 (Table 3):

We did not identify any of the following in our analysis:	
iv)	T-tube common bile duct; biliary or gallbladder cases
v)	urostomy
vi)	nephrostomy
vii)	Abdominal compartment syndrome management: a. Overall fasciotomies n=497 (no recorded abdominal compartment syndrome). b. Non-closure abdomen and non-closure abdomen techniques see. (6.5.2.B: n= 918).
viii)	DNBI in conflict (see Chapter 5): a. hysterectomy b. gallbladder surgery

Part of the proposed NATO curriculum as discussed by the Committee of Chiefs of Military Medical Services, COMEDS 2014 (Hoencamp et al., 2014; Hoencamp 2016).

Table 4: The surgical skill set: a comparison between our study and previously suggested surgical skill sets

Previous suggested abdominal/vascular procedures (Hoencamp et al 2014):	Present study results	Previously suggested thoracic procedures (Hoencamp et al 2014)	Present study results	Previously suggested extremity and pelvic procedures (Hoencamp et al 2014)	Present study results	Previously suggested head neck and neurosurgical procedures (Hoencamp et al 2014)	Present study results
Aortic cross clamping	see: 6.4: n=4	Thoracotomy	see: 6.5. I: n=260	Pelvic binding or external fixation/pelvic packing	see 6.7.V: n=32	Surgical control of major head and neck vessels	see 6.1.b: n=169
Simple ligation of major vessel	see: 6.3	Closure of penetrating cardiac wounds	see: 6.5.I.B	Junctional zone bleed control with urinary catheter tamponade	With urinary catheter tamponade NR; see 6.1.b: n=360	Drainage of cervical oesphageal injuries	NR
Arterial injuries	see: 6.3	Lung haemorrhage control	see: 6.5. I.B: n=70	Articular fracture temporization with bridging external fixator	see 6.7: n=1051	Surgical airway management including tracheostomy	see 6.4: n=101
Venous injury	see: 6.3	en masse lobectomy	see: 6.5. I.B: n=13	Rapid amputation	see 6.7.I: n=982	Intracranial bleeding-emergent hemorrhage control	see 6.4: n=1
Liver laceration	see 6.5.C: n=15	Pulmonary tractotomy	see: 6.5. I.B: n=2	Fracture reduction	see Results 6.7: n=59	Burr hole technique	NR
Colonic perforation	see 6.5.C: n=3	Non-anatomically stapled lung resection (tractotomy)	NR; see Results: 6.5.1	Soft-tissue debridement	see 6.7: n=1931	Intracranial hematoma evacuation	see 6.4: n=1
Removal of spleen and kidneys	see 6.5.C: n=116; n=26	Closure chest wall muscles en masse	NR; see Results:6.7.VII	Contamination minimized by high volume lavage	NR; see Debridement	CNS fragment removal	NR
Bladder ruptures	see 6.6: n=17	Repair of oesphageal injuries	see Results 6.5. I.B: n=7	Compartment syndrome prevention - wide area fasciotomy	see Results 6.7: n=497		
Pancreatic drainage	see 6.5.C: n=3	Temporary closure of thoracic wounds with an iv fluid bag	NR	Soft-tissue coverarge temporary dressings	NR; see 6.6.b		
Irrigation peritoneum	see 6.5.B: laparotomies n=1624)			Management of burns	see Results 6.4: n=227		
Abdomen temporarily closed	see 6.5.B.I: n=682			Primary wound management with vacuum packs	see Results 6.7: n=2444		
				Femoral fracture control with external fixation	see 6.7.I.E: n=14		

Table 4. Comparison of the present study to the suggested surgical skill set by Hoencamp et al., (2014) (Table 2) and adapted from Ramasamy et al., (2010) (see methods for more details). NR – no surgeries of this type specified.

Chapter 7

War surgery experience saves lives: prioritising surgical procedures for armed conflicts and terror attacks

Abstract

Background:

Presently there is no internationally agreed surgical skill-set for war. Sadly, as blast injuries become more prevalent in peacetime, the surgical procedures outlined in the present study are no-longer confined to the military or armed conflicts overseas. We aim to provide the first evidence-based template for surgical procedures that may improve readiness, and standardisation, for future armed conflicts and terror attacks.

Methods:

Of the 10,891 cases, we identified 4821 primary Battle Injury (BI) cases, of which 3136 were primary blast trauma cases. Surgeons were selected based on their involvement in the most serious cases of blast trauma. We identified 40 surgeons who, as a group, were involved in 1951 primary blast surgery cases, 62.2% (n=1951 of 3136), a representative sample. We examined sequentially, each of the blast trauma cases they were involved in throughout the course of the conflict in Afghanistan (2009-2014) and allocated them into two groups: Group A: surgeons involved in more than 50 blast trauma cases (n=1047); Group B: surgeons involved in fewer than 50 blast trauma cases (n=904). We used their case number as a proxy for experience managing blast trauma to examine the impact of surgical experience on case fatalities. For the selected group of 40 surgeons we analysed the operation times for each sequential case and calculated the mean operation time for the group's first case (operation) on a primary blast injured casualty, and cases sequentially thereafter. Sequential cases were analysed and those with operation times greater than 02:30:00 hours were excluded from analysis and sequential operations/case numbers over 100 (i.e. unusually experienced surgeons) were also excluded as insufficient surgeons carried out this many primary blast surgical cases. A template for prioritising surgical procedures was developed through the categorisation of the most frequently performed procedures by anatomical region. In addition, Died of Wounds (DOW) figures were compared to previous conflicts and the effect of casualty demographics on primary surgery for battle injury (BI) casualties was analysed. Statistical analysis with the z-test was used to compare proportions of injuries, nationalities and surgical

procedures with previous studies with different sample sizes. Differences in baseline characteristics and clinical outcomes between study groups were assessed with the use of the chi-square test for categorical variables. We used linear regression analysis to ascertain whether surgical experience (case number) predicted operation time for blast trauma. Significance at the 5% level was accepted ($p<0.05$). The database was approved by the MODREC (Ministry of Defence Research and Ethics Committee).

Results:

We identified the top ten surgical procedures carried out per body region and created a template for prioritising surgical procedures. There were statistically fewer wounded casualties DOW in the present study (latter half of the conflict in Afghanistan 2009-2014) (1.9%) compared to the first half of the conflict 2001-2005 (3.4%) and 2005-2009 (3.4%) (1.9% vs 3.4%; $z=3.464$; $p<0.001$) (1.9% vs 3.4%; $z=4.946$; $p<0.001$) (Owens et al., 2008; Belmont 2012). Statistically there were significantly more casualties that DOW at the start of the conflict in Afghanistan and Iraq (2001-2004) 3.3% compared to the end of Vietnam 2.6% (3.3% vs 2.6%; $z=4.409$; $p<0.001$) despite a decrease in the lethality of wounding (Gawande, 2004). There were significantly more case fatalities in the group of surgeons who carried out less than 50 primary blast trauma cases over the conflict compared to those with more experience [(X^2 (1) = 17.5207; $p<0.001$)]. And an individual surgeon's average time per operation was significantly reduced the greater their prior blast trauma operating experience [linear regression analysis: $F(1,22) = 10.992$, $p<0.01$, $R^2=0.333$]: Less time saves lives. Casualty demographics influenced primary BI surgery operation time, with Afghanistan Population (PAED; EF; CIV; ANSF) cases accounting for the majority of cases >90mins compared to ISAF (47.4%: 31.3% respectively: $p<0.001$). Significantly more ISAF cases were <90mins compared to >90mins (41%: 31.3% respectively: $p<0.001$). Casualty nationality influenced primary Battle Injury (BI) surgery operation time; we show that Afghanistan casualties' (PAED; EF; CIV; ANSF) operations were significantly more likely to have primary BI operation times greater than 90 minutes (47.4%) compared to ISAF (31.3%) (47.4% vs. 31.3%: $z=-25.040$; $p<0.001$). Significantly more ISAF cases lasted for less than 90 minutes (41.0%) compared to over 90 minutes for Afghan casualties (31.3%) (41.0% vs 31.3%; $z=6.994$; $p<0.001$).

Conclusions:

We show that surgeons with more than 50 prior cases of primary blast trauma surgical experience had significantly fewer case fatalities than surgeons with less experience (<50 cases) (X^2 (1) = 17.5207; p<0.001). We show that surgical experience (case number) managing blast trauma significantly predicts reduced mean operation time (F (1,22) = 10.992, p<0.01, R^2=0.333). We suggest that these findings are an explanation for our finding of a significant reduction in the proportion of casualties injured in battle who Died of Wounds at the end of the conflict, compared to the beginning (1.9% vs 3.4%; z=3.464; p<0.001). Therefore, the results of our study show that the current surgical training does not adequately prepare the surgeon for blast trauma, and that a "slipping back" in surgical experience between armed conflicts could lead to increased case fatalities and prolonged surgical times in future armed conflicts. We suggest a dedicated Complex Attack Surgical Team (CAST) is set up in the UK. The CAST team will be ready to carry out the primary surgery at the host trauma centre or local hospital after any bombing, terror attack or other mass casualty event.

Introduction

As blast injuries become more prevalent in peacetime, the surgical skills outlined in the present study are no-longer confined to the military, or overseas armed conflicts (Smith et al., 2017). With the increase in terror-related attacks in cities at home, there is a recognised need to improve readiness for terror attacks in addition to armed conflicts, in order to manage the major trauma which inevitably occurs (Hoencamp et al., 2015; Moran et al., 2017; Smith et al., 2017).

Currently, however, there is no international consensus for the surgical procedures for the trauma seen in armed conflict (Schwab, 2014), and The Committee of Chiefs of Military Medical Services in NATO (COMEDS) have recognised that there is a lack of standardisation, and that the NATO curriculum for the combat trauma surgeon implementation is left up to individual countries to devise (Hoencamp et al., 2015). Meanwhile, The Intercollegiate Surgical Curriculum Programme (ISCP General surgery) recognises that those parties with an 'Advanced Trauma' interest, e.g. military surgeons or those working in a Major Trauma Centre (MTC), need to gain additional competencies, while acknowledging that advanced trauma skills "cannot readily be gained in most UK surgical practice…" (ISCP Oct 2013). Likewise, the syllabus for Paediatric surgeons includes the requirement to be able to perform a trauma laparotomy to the level of 'can do whole but may need assistance', and a trauma thoracotomy to the level of 'can do with assistance': There is no detail of a more comprehensive skill set (ISCP, paediatric surgery). We have suggested a comprehensive skill set template for paediatric trauma procedures training in Chapter 5.

Schwab (2015) showed that when first deployed to a conflict zone, 53.2% of surgeons interviewed had less than 2 years of prior surgical experience. Similarly, 56.8% of respondents of the Eastern Association for the Surgery of Trauma felt the trauma team was not adequately prepared (Schwab, 2015). In general, surgeons requested additional experience in the following injury types: mediastinal trauma (43.1%); extremity vascular (38.0%) and pulmonary trauma (27.7%), amongst others (Schwab, 2015). It is acknowledged that one surgeon is unlikely to be able to do the full complement of surgical procedures required in complex trauma, and this is compounded by increased sub-specialisation of training (Ramasamy et al., 2010; Smith et al., 2017). And yet, 23.7% of surgeons, at the time of their first deployment, were the only surgeon and operated on their own (Schwab, 2015). Put simply, surgical blast trauma experience does not match the needs of the injuries seen in armed conflicts and, increasingly today, in civilian hospitals in the UK.

The rise in terror attacks since the end of combat operations in Afghanistan (2014) has presented a unique challenge for the doctors and surgeons practicing in our local cities (Moran et al., 2017). The Federation of Surgical Specialty Associations (FSSA) recognises that experience is needed to be competent in emergency care, and recommends that surgical training be more generalist in its approach to allow for this (FSSA document 2014). Major trauma training is, however, not prioritised in the UK despite four separate terror attacks having occurred in 2017 alone: Westminster Bridge (22 March); Manchester Arena bombing (22 May), the London Bridge attack (3 June) Parsons Green underground station (15 Sept); (Smith et al., 2017; Moran et al., 2017) involving mass casualties that resulted in 37 deaths and more than 265 people injured [BBC news (2017); (Esri Story Maps (2017); The Guardian (2017); The Telegraph (2017)]. The need for trauma training remains an issue for all medical professionals (Smith et al., 2017). Planning for mass casualty events has been recognised by NHS England, as important. The present study is therefore required, given the increased threat, and likely continuance of attacks, in the near future (Moran et al., 2017).

Lethality of war wounds has reduced over the course of modern conflicts, thanks to incremental gains in Combat Casualty Care (CCC) (Gawande, 2004; Eastridge, 2012). Casualties can now survive previously non-survivable wounds and the reasons for this improvement are currently undefined but are likely to be multifactorial (Palm et al., 2012; Butler and Blackbourne, 2012; Eastridge et al., 2012). Given that in the UK, surgical training hours have been reduced by EU decree, and since most surgeons in the UK haven't had experience of managing blast trauma, it is possible that there exists an initial learning curve with its corresponding, yet preventable, loss of life on arrival to a conflict zone (Ramasamy et al., 2010). Therefore, the surgical experience gained during the conflict in Afghanistan may, in turn, lead to increased survival.

To examine whether current surgical training adequately prepares the surgeon for conflict (and associated blast trauma), the present study aims to assess whether surgical experience obtained whilst in Afghanistan managing blast trauma predicted patient outcome i.e. reduced operation times for Damage Control Surgery (DCS), and/or case fatality rates. Therefore, as the conflict in Afghanistan passes, and the surgical experience fades, the present study also aims to identify the most frequently performed surgical procedures to propose a template for prioritising surgical procedures to improve readiness and reduce preventable loss of life in for future armed conflicts and terror attacks.

Methods

The study was based on surgery that took place at Camp Bastion, Role 3 Medical Treatment Facility, Afghanistan.

From November 5, 2009, to September 21, 2014, we transcribed all prospective entries in operating theatre records (surgical log-books) into an Excel Microsoft software, version 2016. The database is being incorporated into the JTTR Joint Theatre Trauma Registry for validation. In addition, the personal surgical logbooks of plastic surgeons were analysed to validate the results of the theatre log. These are described in Chapter 1 (Maitland et al., 2016). All surgical cases on Disease Non-Battle Injuries (DNBI) were excluded from the present study.

All data fields were transcribed into the database, n=10,891 consecutive surgical cases (see Chapter 3 for further details).

Patient demographics collected included: age; sex; nationality (Afghanistan casualties: Afghan National Security Forces ANSF; civilian adult CIV; paediatric (children <16 years); Enemy Forces EF), and International Security Assistance Force (ISAF). The demographics for this study were grouped as such because ISAF casualties were re-patriated for definitive surgery whereas Afghan casualties returned to the healthcare provision of their country.

The emergency status of each case was recorded along with operation type (primary -first-look; secondary - take-back). The mechanism of injury was recorded for each primary case (operation) and classified as Battle Injury (BI) and sub categorised thereafter as: blast, Gun Shot Wound GSW, Burn, Stab or DNBI Disease-Non-Battle-Injury (DNBI) (included RTA; bites (animal) which were excluded from the present study).

In total, Battle Injured casualties underwent 4821 primary surgical cases, of which 3136 were caused by blast. Time in, and out, of theatre was incompletely documented in 7 cases, therefore duration of cases (operations) available for analysis was 4814. The Damage Control Surgery (DCS) ideal time of 90 minutes (01:30:00 hours) was used as a cut off (Hirshberg 1999; Waibel and Rotondo 2010) to allocate primary Battle Injured cases into three groups based on their operation time: less than or equal to (</=) 01:30:00 hours (n=2188) and greater than 01:30:00 hours (n=2626); and of those >03:33:00 hours. The relationship between casualty, nationality, and primary trauma surgery operation time was analysed.

Local time was used throughout.

Additional columns were added for cases involving proximal vascular control procedures, as was a column which denoted the region of the body on which the surgical procedures were carried out (e.g. BLE (Bilateral Lower Extremity; see appendix).

Performance measures of trauma surgery:

Surgeons were selected for analysis in the first part of this study (n=40) by searching our database for surgical cases which had the Damage Control Surgery criteria: [First, we selected cases that were classified as Battle Injured (BI) casualties and specifically selected those that suffered blast trauma. Secondly, we selected from that the cases where the casualties underwent primary surgery that required proximal vascular control procedures and damage control laparotomy performed in <90 minutes. Thirdly, and to control for severity of injury of casualties, in addition cases where the casualty DOW from injuries sustained by blast mechanism of injury were selected (n=40)].

We identified 14 cases (several surgeons are typically involved in a single case), and the surgeons involved were selected, and their case history throughout the conflict in Afghanistan managing blast trauma was investigated. We created a separate spreadsheet of the database and added columns for the selected surgeons identified so we could analyse their primary blast trauma surgical cases sequentially for the following: operation time (hours); and DOW case fatality.

As a result, we were able to record for individual surgeons, the total number of primary blast BI cases they operated in (Group of selected 40 surgeons were involved in 62.2% of primary blast trauma cases (1951 of total 3136), a representative sample. Selected surgeons were assigned to one of the two groups: Group A surgeons who operated on more than 50 primary blast trauma cases vs. Group B surgeons who operated on less than 50 primary blast cases) without stratification. Surgeons were allocated a letter, and treated anonymously – identity was not an issue. Over the course of the 5-year time period studied, the combat activity, wounding patterns, surgeons, and mission emphasis of the hospital all changed throughout the conflict period.

Surgeons with a minimum of 50 blast surgical case experiences were selected as "expert" surgeons for detailed analysis for the following reasons: 50 was calculated to be the minimum number of cases which ensured appropriate sample sizes for each category to allow meaningful statistical analysis of case fatality rates.

The mean number of primary blast cases for the group of selected surgeons was 50 (case range: 164-11; mean number of cases: 48.775). Fifty experiences is also in line with the literature on skill acquisition and skill fade for intubation (Graham, 2004).

Surgeons' blast trauma case number was used as a proxy for surgical experience and the impact of this on the following outcome measures: case fatality and mean operation time for blast trauma cases.

Of the selected surgeons, we analysed to see whether case fatality rate varied depending on surgical experience managing blast trauma. First, we analysed each surgeons' blast trauma cases sequentially, and the number of primary blast trauma cases where the casualty DOW was calculated between each group (Group A vs. Group B) of surgeons and results were compared. Secondly, to analyse whether surgical experience predicted blast trauma operation time, for the selected group of 40 surgeons we analysed the operation times for each sequential case and calculated the mean average of their times calculated for the group's first case (operation), second, third, etc. on a primary blast injured casualty, and cases sequentially thereafter.

Of the 1951 primary blast cases identified in the group of 40 surgeons, 164 sequential mean operation times were analysed, some surgeons took part in 11 primary blast cases, and only one surgeon was involved in all 164 primary blast surgical cases. Following this, sequential cases were analysed and those with operation times greater than 02:30:00 hours were excluded from the next analysis as were sequential operations/case numbers over 100 as insufficient surgeons carried out this many primary blast surgical cases, and so analysis was limited to up to 100 cases.

We analysed the surgical procedures carried out in extremis, using the same criteria listed above [(primary; BI; blast; required proximal vascular control in the abdominal cavity and DOW (n=14)] to identify the Damage Control (DC) surgical procedures most frequently performed by body region.

Before the study was initiated, the database was approved by the MODREC (Ministry of Defence Research and Ethics Committee).

Data obtained through November 5, 2009, to September 21, 2014 were included in surgical performance analyses. The primary outcome measures were case fatality (DOW) and total operation time (hours).

Body region:

We analysed which body regions were most frequently operated on, and the most frequent surgical procedures carried out per body region. Surgical procedures were divided by anatomical location and can be found in (Fig. 2). In doing so, each procedure was mapped to a different region e.g. if multiple limbs were debrided at any one time, this was recorded as a single procedure per region; but if multiple penetrating fragment wounds affected multiple body regions, each would be recorded as a separate procedure. The body region column, and the index surgical procedures column, was used to analyse the regions of the body most frequently operated upon, and which surgical procedures were carried out. Surgical procedures were mapped according to the frequency performed and anatomical region. This was carried out for primary and secondary battle injury cases.

Body regions were then grouped into the following: chest; abdomen; male genitalia and bladder; buttock perineum and ano-rectal region; head and neck region. Chest region with the heart was analysed separately; as was the viscera within the abdomen region which was also analysed separately: ; bowel; spleen; liver; kidneys; pancreas; omentum; retroperitoneal procedures; abdominal wall closure and non-closure techniques.

Non-compressible haemorrhage regions included: cavities (chest and abdomen) and junctional zones: (groin, axilla and neck) (Chapter 6, Fig. 1). The most frequently affected vessels and vascular procedures were analysed as were which junctional zones were involved in gaining proximal vascular control.

Musculoskeletal region (MSK) included the following body regions: leg (lower extremity); arm (upper extremity); torso/flank; hand; buttock, perineum and ano-rectal region (as above); foot and ankle; shoulder; calf, tibia and fibula; knee and hip and femur (regions and procedures not in the top 10 were not included in the template).

Case fatality:

The percentage of casualties that DOW in the present study was calculated to enable comparison with previous studies: the number of casualties that DOW (Battle Injury (BI)) (n=95) after reaching Camp Bastion, Role 3 Medical Treatment Facility, as a percentage of BI wounded casualties (n=4821) that arrived at the surgical field hospital, in a manner consistent with previous studies.

Lethality of wounding analyses was not carried out for the present study, as we do not know the proportion of those injured on the battlefield (civilians and combatants), that later DOW at either the Camp Bastion Trauma Centre, Afghanistan, or other hospitals during the study period.

Statistical analysis:

Statistical analyses were performed with the use of Excel Microsoft software, version 2016. Standard descriptive statistics were used to calculate the frequencies, means, and standard deviations of the study variables. Differences between study groups in baseline characteristics and clinical outcomes were assessed with the use of Chi-square tests and were used for categorical variables. Multivariate linear regression analyses, adjusted for baseline scores, were used to examine the effect of sequential case/operation number (as a proxy for surgical experience) and operation time. The z-test was used to compare proportions of injuries, nationalities, and surgical procedures, with previous studies with different sample sizes. Significance at the 5% level was accepted ($p<0.05$). We calculated the percentage of casualties that DOW, as described above.

Results

There was a significant decrease in the percentage of casualties that DOW in the present study, 2009-2014, (1.9% n=95 of 4821) compared to DOW figures from the first half of the conflict 2001-2004 ($p<0.001$) and 2005-2009 ($p<0.001$) (Gawande 2004; Belmont et al., 2012) There were statistically fewer wounded casualties DOW in the present study (latter half of the conflict in Afghanistan 2009-2014) (1.9%) compared to the first half of the conflict 2001-2005 (3.4%) (Owens et al., 2008) and 2005-2009 (3.4%) (Belmont et al., 2012) (1.9% vs. 3.4%; $z=3.464$; $p<0.001$; Fig.1a; Table 1) (1.9% vs. 3.4%; $z=4.946$; $p<0.001$; Fig.1a; Table 1) (Gawande 2004; Owens et al., 2008; Belmont et al., 2012).

Statistically there were significantly more casualties that DOW at the start of the conflict in Afghanistan and Iraq (2001-2004) (Gawande 2004) 3.3% compared to the end of Vietnam 2.6% (3.3% vs. 2.6%; $z=4.409$; $p<0.001$; Fig.1a; Table 1) despite a decrease in lethality of wounding (Fig.1b) (Gawande, 2004).

There was no significant difference in the DOW percentage during the first half of the conflict in Afghanistan: 2001-2004 (3.3%) compared to 2001-2005 (3.4%) (3.3% vs. 3.4%; $z=-0.207$; $p>0.05$; Table 1; Fig.1a) nor between 2001-2005 3.4% and 2005-2009 3.4% (3.4% vs. 3.4%; $z=0.000$; $p>0.05$; Table 1; Fig.1a).

Figure 1b shows the lethality of wounds (proportion of casualties Killed in Action (KIA) as a percentage of casualties wounded) has been decreasing over the course of previous conflicts, from 24% Vietnam (1961-1973), and 24% Persian Gulf war (1990-1991) to 10% in the first half of the conflict in Iraq and Afghanistan (Fig.1b; Gawande 2004).

An estimation of the surgical experience over time is superimposed upon Fig. 1c.

Figure 2 shows the template for prioritising surgical procedures in war and details the comprehensive analysis of the surgical procedures most frequency performed in primary and secondary BI cases, and categorises them by body region - data for the period 2009-2014.

A total of 40 surgeons were selected for their involvement in the most serious blast trauma cases (see methods for further details) and were allocated to two groups (Figure 3: Group A vs. Group B) based on their surgical experience managing blast trauma (the number of primary blast cases they performed during 2009-2014). The selected group of surgeons were involved in a total of 1951 blast trauma cases. We examined each of the blast trauma cases they were involved in sequentially throughout the conflict and allocated them into two groups: Group A: surgeons (12) involved in more than 50 blast trauma cases (n=1047); Group B: surgeons (28) involved in less than 50 blast trauma cases (n=904).

We used their case number as a proxy for surgical experience managing blast trauma to examine the impact of surgical experience on case fatalities.

For each surgeon, the number of case fatalities for primary blast trauma cases they were involved in was recorded and a total in each group was calculated. There were 20 deaths from blast trauma in the Group A surgeons, and there were 49 deaths from blast trauma in Group B surgeons (Fig. 3).

A chi-square test of independence was calculated comparing the frequency of case fatalities between the two groups of surgeons divided by their experience managing blast trauma (Group A vs. Group B). A significant relationship was found between surgical experience and case fatality (X^2 (1) = 17.5207; p<0.001).

Significantly more case fatalities occurred in Group B surgeons with less than 50 primary blast trauma cases (less experience) compared to Group A surgeons with greater than 50 primary blast trauma cases, and therefore more experience. [(X^2 (1) = 17.5207; p<0.001)].

We assessed the standardisation in approach to trauma surgery, first through analysing operation time for primary BI casualty's trauma surgery (Table 2). We found a wide range of operation-time lengths for Damage Control Surgery (Table 2). We analysed the proportion of primary BI cases that had surgery >01:30:00 hours and found that the majority, 54.5%, had operation lengths >01:30:00 hours, with less than half of all primary BI surgery completed in <01:30:00 hours, 45.4% (Table 2). For initial trauma surgery, 15.1% had operation times >03:33:00 hours (Table 2). When we analysed operation times of cases where casualties DOW, we found that 33.7% of casualties who DOW had operation-time lengths > 01:30:00 hours, and 5.2% of casualties that DOW had operation-time lengths > 03:33:00 hours (Table 2).

Next, we analysed the standardisation in trauma surgery through analysing the effect of casualty demographics on primary surgery for battle injury (BI) casualties (Table 2). Operations on Afghanistan casualties (PAED; EF; CIV; ANSF) were significantly more likely to have primary BI operation times greater than 01:30:00 hours (47.4%) compared to ISAF (31.3%) (47.4% vs. 31.3%: z=-25.040; p<0.001; Table 2). Afghanistan population casualties were significantly more likely to have trauma surgery operation times greater than 01:30:00 hours (47.4%) compared to less than 01:30:00 hours (38.2%) (47.4% vs. 38.2%; z=6.416; p<0.001; Table 2). International Security Assistance Force (ISAF) casualties were significantly more likely to have operation times less than 01:30:00 hours (41.0%) compared to greater than 01:30:00 hours (31.3%) (41.0% vs. 31.3%; z=6.994; p<0.001; Table 2:). There was no significant difference between the proportion of Afghanistan casualties with primary BI surgery operation lengths <01:30:00 hours (38.2%) compared to ISAF (41.0%) (38.2% vs. 41.0%; z= 1.894; p>0.05; Table 2). Afghanistan casualties made up a disproportionate proportion of the primary blast surgical cases >01:30:00 hours compared to ISAF cases <01:30:00 (47.4% vs 41.0%; z=4.449; p<0.001).

Table 3 highlights the surgical procedures most frequently identified as being performed on the most severe blast trauma cases (see methods search-criteria: primary, BI, proximal vascular control, Died of Wounds: n=14 cases) and categorised these procedures by body region: cavities and extremities and suggest a cross-specialty core-skill set for trauma.

Given the wide variation in approach to trauma surgery recorded above, initially, when we analysed for the effect of surgical experience managing blast trauma on operation time (hours), we found that, as the surgical experience (blast case number) of the group of surgeons (selected for their involvement in the most severe blast trauma) increased, there was no discernible significance in experience predicting operation length (Fig.4: overall regression model was insignificant, (F (1, 162) = 36.038, p=1.23E-08, R^2=0.182).

Figure 4 shows the mean operation time for the group of selected surgeons' sequential cases up to 164. Surgical experience (sequential blast trauma case number) did not statistically significantly predict the mean operation time (hours) (Fig.4: p>0.05).

However, Figure 4 shows that there was only one surgeon in the selected group that performed 164 blast trauma cases, and that there were some cases with operation times of >02:30:00 hours. Therefore, the mean operation time for the sequential cases in the group of surgeons were analysed further, and those with operation times greater than 02:30:00 hours were excluded from analysis and sequential operations/case numbers over 100 were also excluded, as insufficient surgeons carried out this many primary blast surgical cases (see methods for further details). Therefore, of the 3136 primary blast cases documented, 1951 cases were identified in the selected group of 40 surgeons, and after cases lasting more than 02:30:00 hours were excluded and cases >100, 265 blast trauma cases remained. The mean sequential cases contributed to 24 separate mean operation times for cases 1-100. This data is portrayed sequentially for the case number in the group surgical history where the above criteria were met (Fig.5).

We show that as surgeons increased their surgical case number (experience) for primary blast trauma, the average operation time significantly reduced in length from about 144 minutes with little experience down to 115 minutes with over 80 prior operational experiences [regression analysis is significant, $F(1,22) = 10.992$, $p<0.01$, $R^2=0.333$; Fig. 5]. Sequential blast trauma case number was found to significantly predict the mean operation time (Hours) (Fig.5: $p<0.05$). Blast trauma experience was also found to predict operation time.

Key findings:

An individual surgeon had fewer deaths the greater their prior operating experience managing blast trauma [a significant interaction was found between blast surgical experience and case fatality X^2 (1) = 17.5207; $p<0.001$; Fig.3].

An individual surgeons' average time per operation is significantly reduced the greater their prior operating experience managing blast trauma [regression analysis $F(1,22) = 10.992$, $p<0.01$, $R^2=0.333$; Fig.5]: Less time saves lives.

Discussion

There has been a recognised drop in lethality of wounding over the course of modern conflicts since Vietnam, the first Gulf War, and the beginning of the conflict in Iraq and Afghanistan (Gawande, 2004). This is despite the severity of wounding patterns changing; blast injuries combined with penetrating, blunt trauma and burns caused by modern Improvised Explosive Devices (IED) typified in the conflict in Afghanistan. The reasons for this drop in lethality are likely to be multi-factorial and include advances in CCC (Palm et al., 2012; Butler and Blackbourne, 2012; Eastridge et al., 2012; Gawande 2004). However, we show that the DOW percentage rose significantly at the start of the conflict in Iraq and Afghanistan compared to Vietnam (see Fig.1a) despite reduced lethality of wounding (see Fig.1b). We also show that our data entered between (2009-2014), compared to similar studies of preceding years of the conflict (2001-2009), shows a significantly lower DOW percentage (Fig. 1a; 1c; Table 1.) (Belmont, 2012; Owens et al., 2008).

The most kinetic period of the conflict in Afghanistan was in 2009, when the percentage of combat casualties was at its highest (0.43%) (Belmont et al., 2012). A significant difference still exists between 2005-2009 (see Belmont et al., 2012) and our findings for the period 2009-2014 (Fig.1a), which suggests that perhaps other factors aside from patterns of wounding were at play.

We anticipated a fall in surgical experience between armed conflicts (Fig.1b), and so we wanted to see whether cumulative surgical experience gained by surgeons during the years of the conflict had any effect on the outcome measures of case fatality and/or operation time. We selected surgeons who were involved in the most severely injured blast trauma cases and analysed their surgical record during the conflict (Fig.3). We found that as the surgeon's experience of blast injury increased, the mean operation time decreased (Fig.5). Sequential blast trauma case number significantly predicts the mean operation time for blast trauma (hours) [regression model was significant, $F(1,22) = 10.992$, $p<0.01$, $R^2=0.333$ Fig.5]. In addition, selected surgeons were categorised into two groups (A and B) based on the number of blast cases they performed (Fig.3: A >50; B<50). Significantly more case fatalities occurred with surgeons who had less blast surgical experience (less than 50 primary blast cases; Group A) compared to those surgeons who had more experience (more than 50 blast cases Group B) [a significant interaction was found between surgical experience and case fatality; X^2 (1) = 17.5207; $p<0.001$) Fig. 3].

We suggest that these results support the theory that a fall in surgical experience between conflicts (so-called "slipping back"; Fig. 1c) accounts for the raised DOW rates at the start of conflicts compared to the end (Fig.1a). The findings of the present study show that there is a relationship between deaths and surgical experience, and operation time (hours) (Fig. 3; Fig. 5). We suggest that the fall in surgical experience between conflicts, such as now, could lead prolonged surgical times, and otherwise preventable deaths, when surgeons are deployed in the next conflict. This is clearly of concern for surgical management of blast injuries as seen in recent mass-casualty events, explosions and the carnage seen in terror attacks in the UK. These findings support the view that current surgical training does not adequately prepare the surgeon for blast trauma. Surgeons who returned from armed conflict felt they had been underprepared with only 2 years of experience before deployment (Schwab, 2015).

The implications for our findings that there is a universal lack of standardisation in surgical approach to trauma (Table.2), and that blast trauma surgical experience predicts operation times, and case fatalities, are far reaching (Fig. 3; Fig.5). With the rise in terror attacks in 2017 alone, how we standardise, and deliver, trauma care in complex violent events, like the Manchester Arena bombing, has become a national responsibility (Moran et al., 2017). Already, Major Trauma Centres (MTCs) optimise care for the most injured patients in the UK, and from 2018 two fellowships in trauma are being offered in resuscitative surgery (surgery specific), and the development of Major Trauma Consultant (not surgeon-specific) (Smith et al., 2017). However, in the wake of the Manchester Arena bombing, the burden of blast injuries was such that one hospital, in ten days, used 139 hours of operation time by surgeons who were blast trauma naïve and whose teams were changed daily (Smith et al., 2017). In addition, future patients from mass casualty incidents will challenge any MTC when multiple ambulances may arrive within a few minutes and/or hours (Smith et al., 2017). Therefore, the present study, proposes a template for prioritising surgical procedures, which should enable a standardisation of trauma care and training, and improve readiness for future armed conflicts, and terror attacks in the UK.

The present study showed that there was variation in primary Battle Injury (BI) surgery operation times between Afghanistan casualties and ISAF, with significantly more trauma cases taking more than 01:30:00 hours on Afghan casualties than ISAF (47.4% vs. 31.3%: $z=-25.040$; $p<0.001$; Table 2). We suggest that this might relate to the fact that ISAF casualties were routinely re-patriated/evacuated from Afghanistan for definitive surgery. Afghan casualties who, by necessity were typically returning to a relative lack of medical care facilities, underwent longer operation times, perhaps to enhance the patients' chances of recovery in their own home/town.

We hope that the template for surgical procedures presented here helps to bring about a standardised approach to trauma surgery. It is necessary to work towards a standardisation of trauma care and improve surgical training (Schwab, 2015; Ramasamy 2010; Hoencamp et al., 2015; Moran et al., 2017; Smith et al., 2017). Courses, simulation training [(Definitive Surgical Trauma Skills (DSTS) courses; Definitive Surgical Trauma Care (DTSC) courses and Military Operational Surgical Training course (MOST)] and fellowships all go some way towards this, but the findings of the present study show that they do not replace the raw blast trauma surgical experience that the present study suggests is needed to prevent case fatalities in the future. In the UK, major trauma training is often not prioritised due to the presumed low chance that these skills in civilian practice would be required, but with the increase in terror attacks the tide is turning (Moran et al., 2017 Smith et al., 2017).

We provide evidence for the reality of skill fade in surgeons (Khan et al, 2017), and, as surgeons are working to gain the necessary surgical experience managing blast wounds patients die. We predict that this skill atrophy may also be the case in other specialities e.g. anaesthetics, emergency medicine, radiology etc., and that unless corrected, more lives will be lost.

The overall success story of the Afghanistan conflict is that casualties have survived previously un-survivable injuries. My thesis highlights the impact and importance of relevant prior surgical experience on survivability.

In order to address the problem of skill fade, we suggest that a Complex Attack Surgical Team be assembled. This team would be made up of known surgeons within the UK with the prerequisite experience of having managed at least 50 blast cases. This group of experts would be placed on a rota accompanied by anaesthetic and transfusion experts at 3-month readiness to respond to any terror attack or mass-casualty event. Other models are available, such as UK Search and Rescue (UKSAR) teams of known experts who form part of a rota on 3-month high readiness (Gov.uk, 2018). With the NHS under increasing strain, we hope that the findings of my thesis result in trauma up-skilling, and not diversion of resources.

We recognise that there is a big difference between skill dilution and "never had the skill in the first place", but also acknowledge that not all surgeons need the skills outlined here. We suggest that this surgical template be used to inform future surgical training curricula and planning, and to enable military planners to make risk-assessed decisions that ensure that they intelligently deploy the surgical team during contingency operations or future armed conflicts, who have the right combination of surgical skills and that individual surgeons have evidence of these competencies.

We provide the evidence base behind the surgical skills required in training new surgeons, it is perhaps unrealistic to rely on combat experience alone to gain the requisite skill set this thesis outlines.

Despite increased traction from NHS England for improved trauma training, we do not experience enough trauma in the UK (Moran et al., 2017). An example of how, in addition to CAST, my data can be used is through Virtual Reality (VR), since we now have the evidence for the most common procedures, by anatomical region, so a surgeon or team could practice, carrying out the following, under time-constraints.

For example, the following combination of procedures used most frequently to surgically manage a casualty injured by blast:

Bilateral Above Knee Amputations
Perineal and buttock soft-tissue debridement and Negative Pressure Wound Therapy (NPWT) dressings
Vascular control procedures in the groin and exploratory abdominal laparotomy for proximal vascular control
Unilateral Upper Extremity Amputation
Chest drain insertion

In addition, we hope that the template facilitates the introduction of a NATO curriculum for the minimum skill set for military surgeons, and recognise that individual NATO countries may wish to implement the proposed standard skill set in their own way.

We hope that the template for surgical procedures in future armed conflict and terror attacks will improve preparedness, as the evidence-based set of competencies it presents may lead to standardisation of the skill set requirement for the trauma surgical team in the event of major incidents or terror attacks in the UK.

The suggested new template for prioritising surgical procedures (Fig.2) may concomitantly, with improved training, lead to reduced case fatality rates in future armed conflicts and terror attacks. The template forms the basis for recommendations to improve surgical readiness for future armed conflicts and terror attacks as follows:

Recommendations:

1) Prior to deployment to armed conflicts, military surgeons require prior experience of more than 50 primary blast trauma cases
2) We suggest that in the UK at least, a dedicated Complex Attack Surgical Team (CAST) be assembled. The CAST surgeons, each with the requisite prior experience of more than 50 primary blast trauma cases, will be ready, and able, to go to the site of any terror attack, mass casualty event, or bombing and carry out the primary surgery at the host trauma centre or local hospital.

Conclusion

The emphasis of the present study is on military surgeons. The Royal College of Surgeons (RCS) has a subspecialty acknowledgement of military surgery, and while they acknowledge the need for additional competencies, the RCS does not stipulate which skills, in particular, the military surgeon should possess (see also Hoencamp et al., 2015). Military surgeons, however, train in the NHS, and go on to practice in the NHS during peace-time. There needs, therefore, to be more focus on some, or all, of the surgical procedures our template indicates are required in order to effectively manage blast/explosive injuries, and to prevent death. Training in these procedures would benefit both the military and civilian surgeons across the board.

We hope that the surgical template suggested here stimulates an international discussion, future agreement, and standardisation on the surgical skills required for dealing with blast trauma. We also hope that surgeons with more than 50 cases of blast trauma experience make up part of any team that can be deployed, either in military conflicts, or, within the UK/other countries as part of the proposed CAST initiative. We show that there is a significant rise in case fatality at the start of conflicts compared to the end, and lower case fatality rate at the end of the conflict than the start. We believe that this is evidence for a "slipping back" in surgical experience between conflicts. Whilst CAST can provide a stop-gap for terror-attacks that occur in the intervening years, the template we provide will hopefully aid NATO to move forward with a standardisation of surgical skills for conflict, and inform future surgical training practices to train, maintain and prepare for complex attack preparedness and terror attack readiness caused by explosions.

Figures and Tables

Figure 1a Casualty death after reaching surgical treatment facilities during the conflict in Afghanistan compared to the end of the Vietnam War

Fig. 1a: Comparison of percentage of casualties that Died of Wounds (DOW) between the present study and previous years of conflict in Afghanistan, and other armed conflict (see also Table 1).

Figure 1b Lethality of war wounds across conflicts

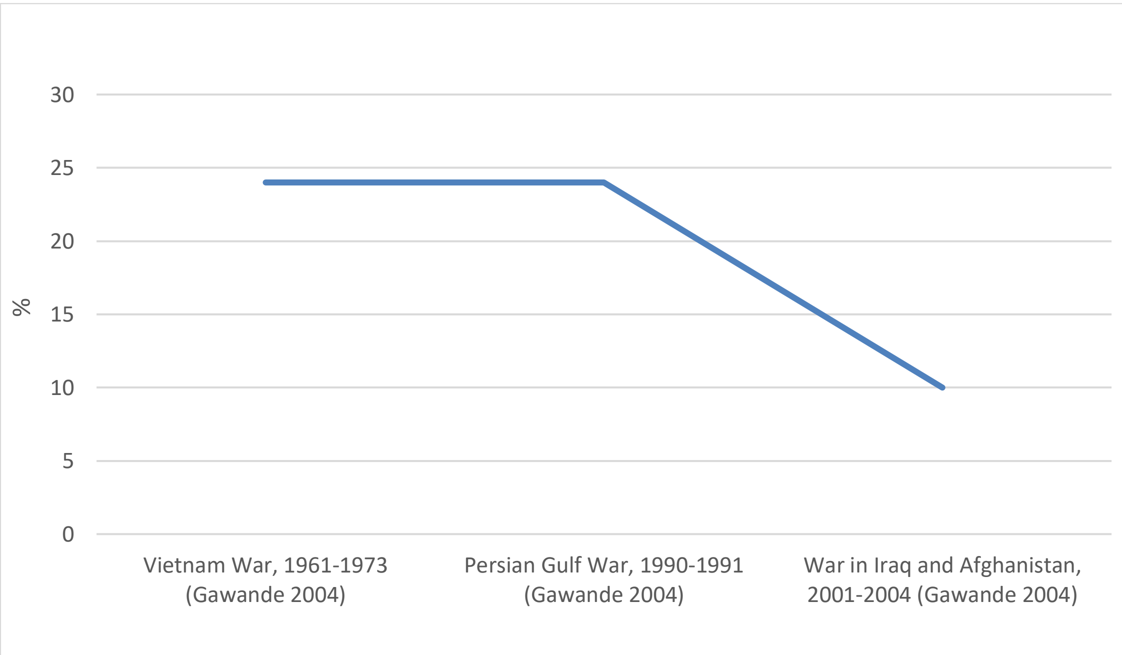


Fig. 1b: Lethality of war wounds expressed as a percentage over the course of three conflicts (casualties killed in action as a proportion of the total number wounded) (Gawande, 2004) (see also Table 1).

Figure 1c Anticipated relationship between surgical experience and case fatalities

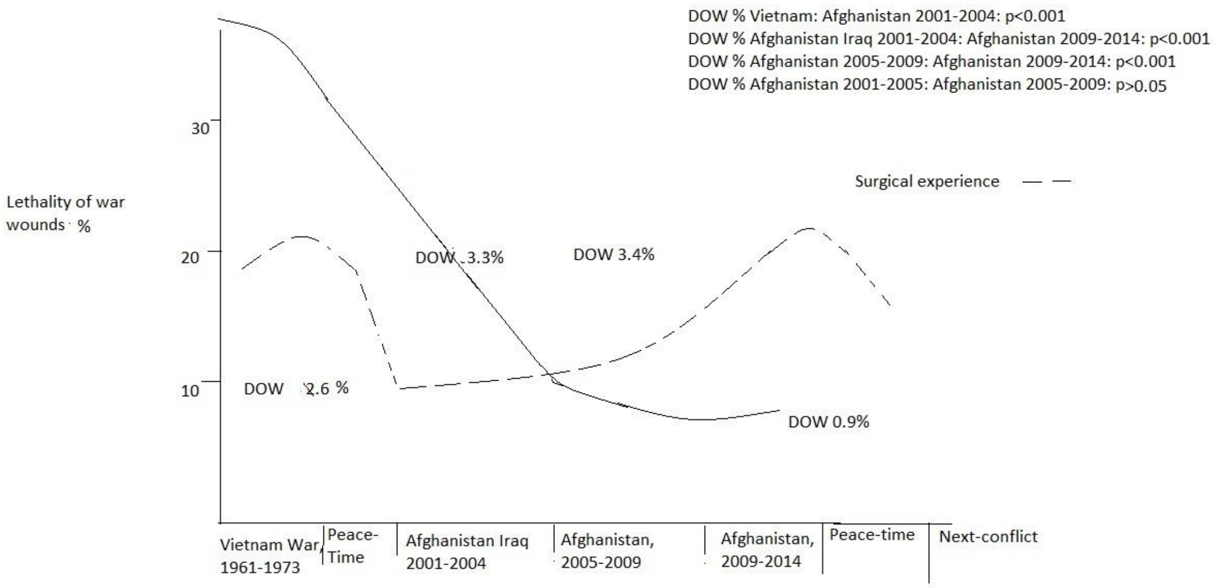


Fig. 1c: An estimation of the change in surgical experience over time (dashed line) is superimposed to show the anticipated surgical experience drop off (“slipping back”) between conflicts. Periods of peace-time coincide with raised Died of Wounds (DOW) rates at the start of subsequent conflicts. DOW rates also drop towards the end of conflict.

Table 1 Proportion of casualties that Died of Wounds (DOW) having reached surgical treatment facilities across conflict in Afghanistan compared to the end of the Vietnam War

	A	B	C	D	E		
	Vietnam	Iraq-Afghanistan	Iraq-Afghanistan	Afghanistan	Afghanistan		
	1961-1973 (Gawande 2004)	2001-2004 (Gawande 2004)	2001-2005 (Owens et al., 2008)	2005-2009 (Belmont 2012)	2009-2014 Present Study	z-value	p-value
Total Battle Injured casualties that arrived at surgical facility	200727	10726	1566	7877	4821		
% DOW After they reached the surgical facility	2.6% (5219)	3.3% (357)	3.4% (54)	3.4% (272)	1.9% (95)	A vs B 4.409 B vs C -0.207 C vs D 0.000 C vs E 3.464 D vs E 4.946 B vs E 4.839 A vs E 3.028	0.000* 0.836 1.000 0.001* 0.000* 0.000* 0.002*

[*(p<0.05)]

Table 1: The proportion of casualties who died of their wounds (DOW) after they reached the surgical treatment facility from Vietnam, and over the course of the conflict in Afghanistan compared to the present study. Of the 10,891 cases in the present study, 4821 were primary surgical cases on Battle Injured casualties, and of those, 95 DOW.

Figure 2: Template for prioritising surgical procedures in conflict

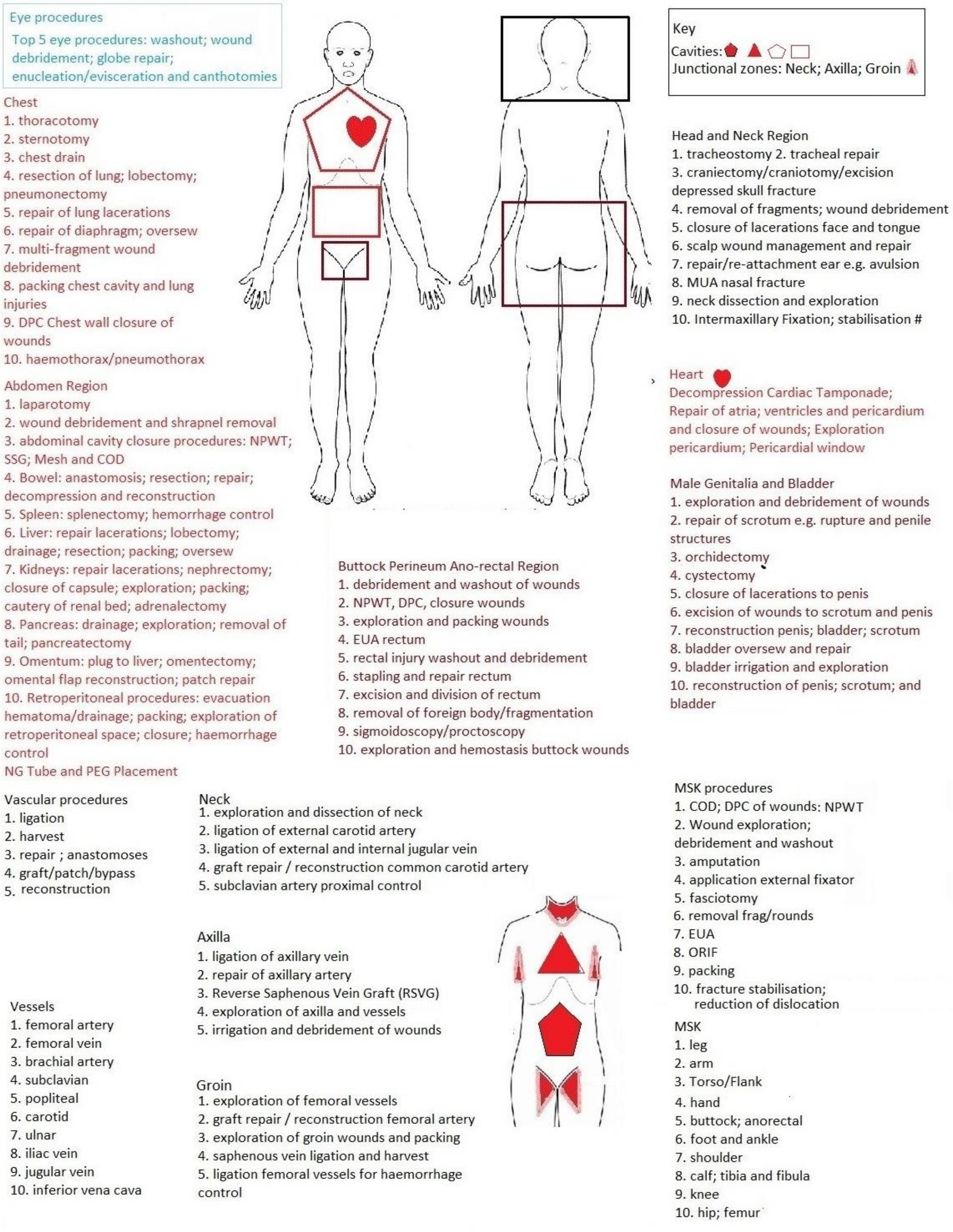


Fig.2: Template for prioritising surgical procedures in conflict. EUA Exploration Under Anaesthesia; ORIF Open Reduction and Internal fixation; DPC Delayed Primary Closure; NPWT Negative Pressure Wound Treatment; COD Change of Dressings; MUA Manipulation Under Anaesthesia; SSG Split-Skin Graft and NG tube Nasogastric Tube. We analysed which body regions were most frequently operated on, and the most frequent surgical procedures carried out per body region. Surgical procedures were

divided by anatomical location and each procedure was mapped to a different region. Surgical procedures were mapped according to the frequency performed and anatomical region. This was carried out for primary and secondary battle injury cases. The most common surgical procedures performed on a given region are ranked in descending order from 1-5 or 1-10.

Table 2. Relationship between duration (hours) of primary Battle Injury trauma cases and proportions of casualties that died of wounds, and casualty nationality.

	</=01:30:00 hours %			> 01:30:00 hours %			> 03:33:00 hours (200 mins)		
Duration of surgery for DOW cases % (n=95)	66.3% (54/95)			33.7% (63/95)			5.2% (5/95)		
Duration of surgery for Primary BI cases (n=4821) %*	(2188/4814) 45.4%			(2626/4814) 54.5%			(725/4814) (15.1%)		
Nationality	A. Afghan 836/2188 38.2%	B. ISAF 898/2188 41.0%	N 454/2188 20.7%	a. Afghan 1246/2626 47.4%	b. ISAF 823/2626 31.3%	N 557/2626 21.2%	i. Afghan 288/725 39.7%	ii. ISAF 304/725 41.9%	N 133/725 18.3%
z-value p-value	A. vs. B. z=1.894 p>0.05	B. vs. b. z=6.994 p<0.001		A. vs. a. z=6.416 p<0.001	a. vs. b. z=25.040 p<0.001				

Table 2: Relationship between duration (hours) of primary Battle Injury (BI) trauma cases (operations) and proportions of casualties that DOW and casualty nationality. N= Nationality not recorded; Afghan includes Afghanistan casualties: Afghan National Security Forces (ANSF), civilian adults (CIV+INTERP), paediatric (PAEDs) and Enemy Forces (EF)

Operations (cases) were categorised into time cohorts: Total primary Battle Injury (BI) cases 4821 of which *time in and out of theatre was incompletely documented in 7 cases (4821-7 = 4814), therefore total cases categorised by time was as a proportion of 4814: less than or equal to (</=) 01:30:00 hours (n=2188) (Damage Control Surgery cut-off see methods for further details) and greater than 01:30:00 hours (n=2626), and of these, those greater than 03:33:00 hours (n=725). We compared the proportion of primary Battle Injury (BI) cases within each time frame between casualty populations not wearing body armour (Afghanistan population) vs. casualty population wearing body armour (ISAF).

Table 3 An analysis of the most severe trauma cases

Primary damage control cross-specialty surgical procedures to stop bleeding and control contamination
1. Abdominal cavity: Laparotomy – proximal vascular control; packing and haemorrhage control and procedures to: Intestines (mesenteric and bowel decompression); spleen; liver, kidneys; retroperitoneum
2. Chest cavity: Thoracotomy – resuscitative and procedures: decompression of pericardial tamponade; packing of lung injuries and repair of atria, ventricles and pericardium; ligation of major vessels and chest drain insertion
3. Extremities: Amputation – completion of amputation Upper Limb and Lower Limb; Pelvic # - ex-fix; ligation of major vessels extremities; fasciotomy; debridement of wounds

Analysis of the most severe trauma cases (search criteria: primary, BI, proximal vascular control, Died of Wounds: n=14 cases), and the surgical procedures most frequently carried out. The surgical procedures are categorised by cavity and extremity.

Figure 3 Relationship between blast trauma surgical experience and case fatality

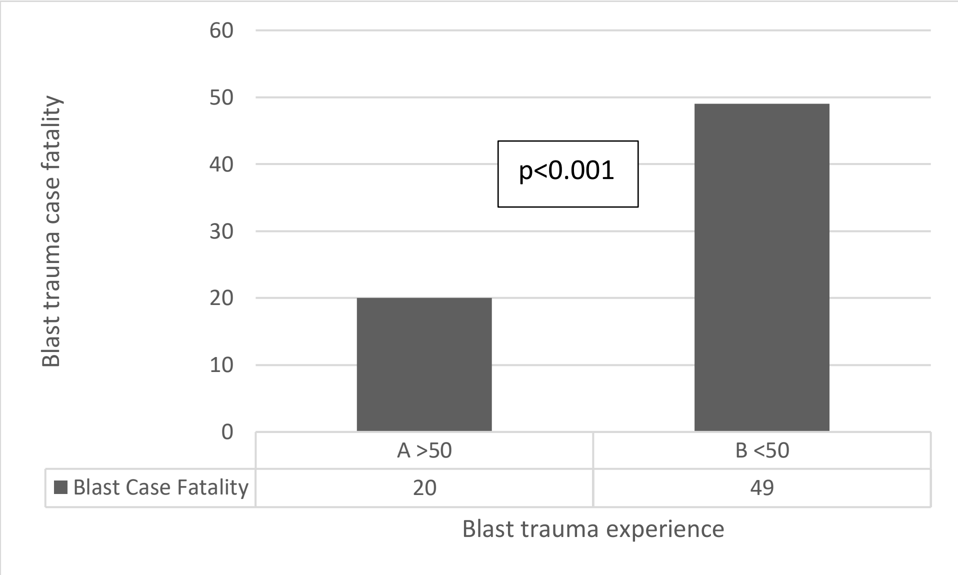


Fig.3: Relationship between blast trauma surgical experience and case fatality. The surgeons selected for analysis on the basis of their involvement in the most severely injured casualties (n=40) and their surgical case history was analysed (n=1951 primary blast surgical cases) were categorised into two groups of surgeons as follows based on their prior experience surgically managing blast trauma casualties during the years of the conflict 2009-2014. Group A: surgeons with experience operating on more than 50 primary blast injured casualties (n=12), and Group B: surgeons with less than 50 primary blast trauma case experience (n=28). For each surgeon, the number of case fatalities for primary blast trauma cases they were involved in was recorded. Group A surgeons had 20 and Group B surgeons had 49 deaths. Comparing Group, A vs Group B, we found a significant correlation between surgical experience and case fatality (X^2 (1) = 17.5207; $p<0.001$).

Figure 4 Mean operation time for blast trauma cases

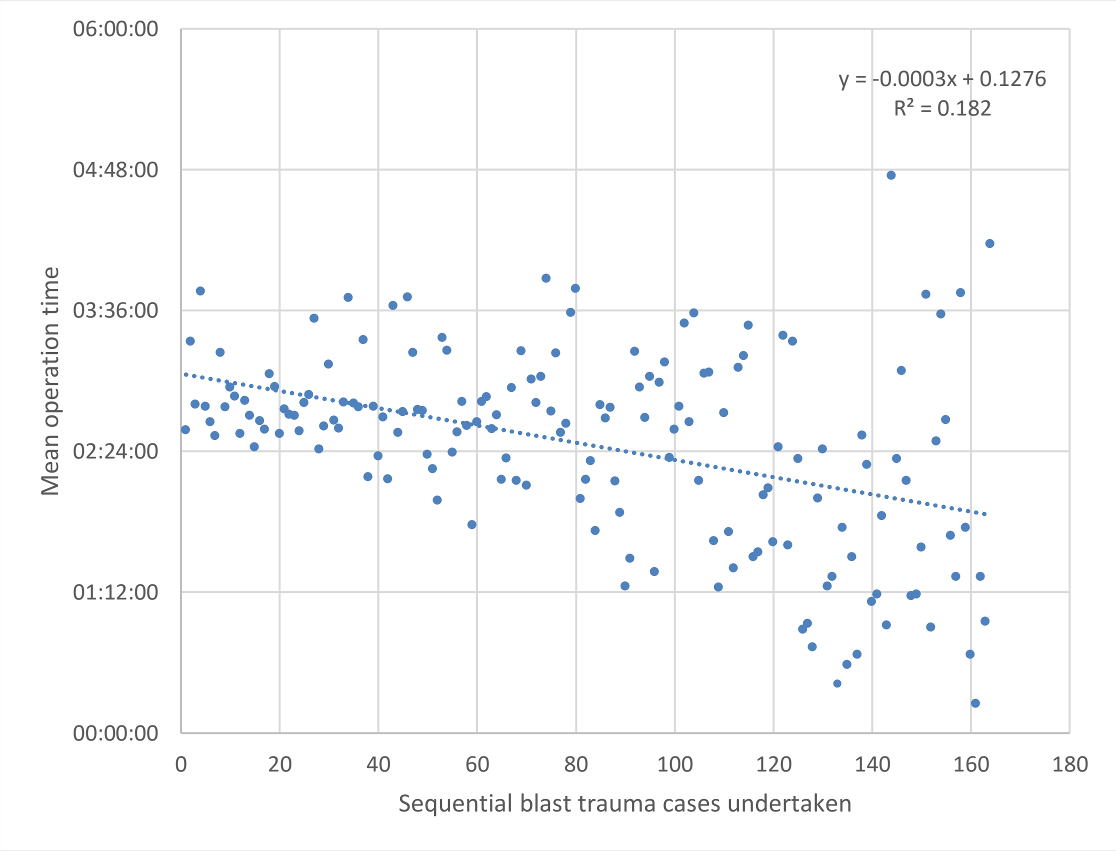


Fig. 4: Correlation between mean operation time for blast trauma cases (operations) in a selected group of surgeons and surgical experience. Each data point represents the mean operation time for a selected group of 40 surgeons for their first case on primary blast injured casualties, and cases sequentially thereafter. Surgeons were selected based on their involvement in the most severely injured blast casualties (see methods). Sequential operations were analysed, and of the 3136 primary blast cases overall, 1951 primary blast cases were identified involving the group of 40 surgeons. 164 separate sequential mean operation times were analysed (only one surgeon carried out 164 primary blast cases). This data is portrayed sequentially for the case number in the group surgical history where the above criteria were met. See summary output below which shows the mean operation time for a group of selected surgeons sequential cases up to 164. Linear regression analysis is not statistically significant ($p>0.05$). Sequential blast trauma case number did not significantly predict the mean operation time ($p=1.23E-08$). The overall regression model was insignificant, $F(1, 162) = 36.038$, $p<1.23E-08$, $R^2=0.182$.

Figure 4 Linear regression analysis:

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.426585
R Square	0.181975
Adjusted R Square	0.176926
Standard Error	0.030886
Observations	164

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.034378	0.034378	36.03797	1.23E-08
Residual	162	0.154538	0.000954		
Total	163	0.188916			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.127555	0.004846	26.32321	2.12E-60	0.117986	0.137123	0.117986	0.137123
case number	-0.00031	5.09E-05	-6.00316	1.23E-08	-0.00041	-0.00021	-0.00041	-0.00021

Figure 5. Correlation between mean operation time (<02:30:00 hours) for blast trauma in a selected group of surgeons and surgical experience

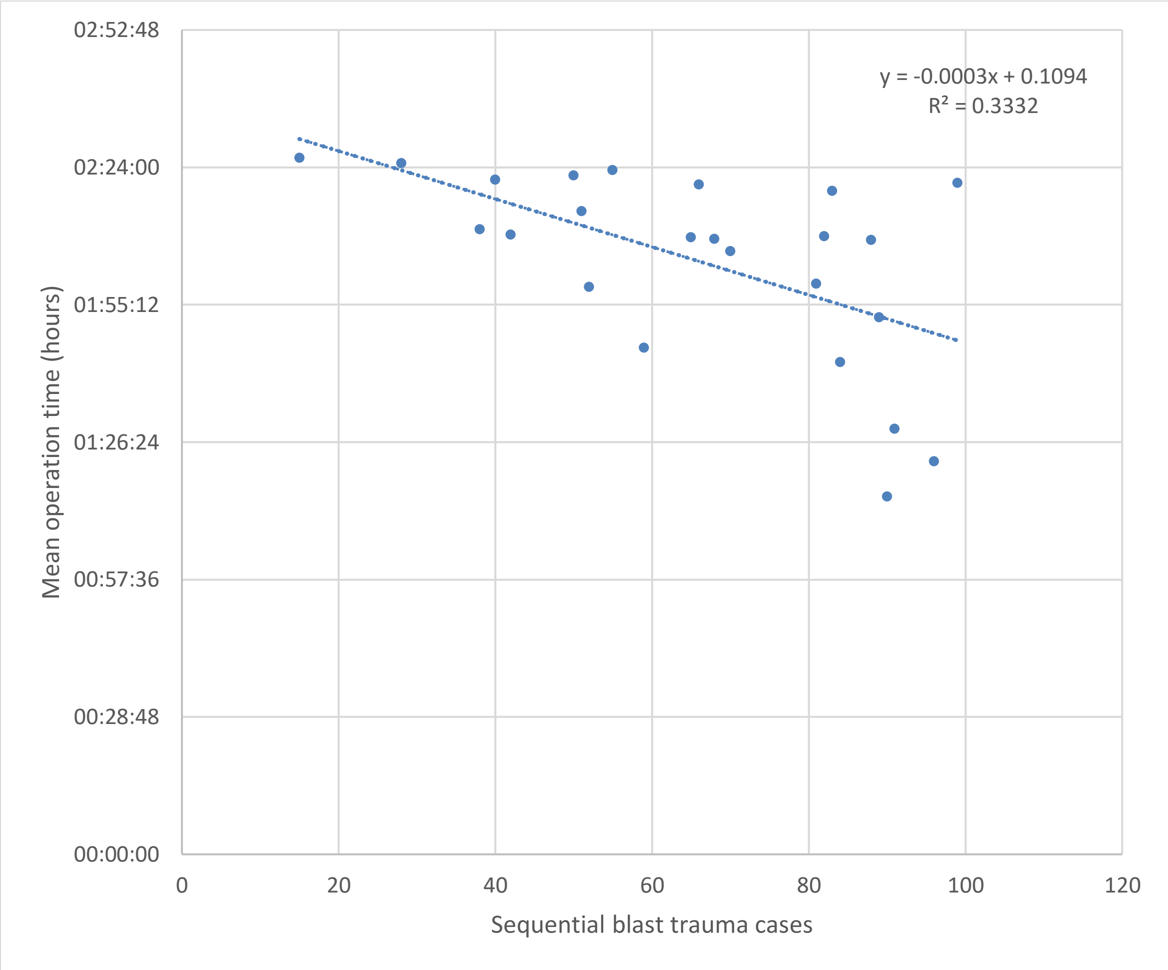


Fig.5: Correlation between mean operation time (<02:30:00 hours) for blast trauma in a selected group of surgeons and surgical experience. Each data point represents the mean operation time for a selected group of 40 surgeons for their first operation/case on primary blast injured casualty, and cases sequentially thereafter. Surgeons were selected based on their involvement in the most severely injured blast casualties (see methods). Sequential cases were analysed and those with operation times greater than 02:30:00 hours were excluded from analysis and sequential operations/case numbers over 100 were also excluded as insufficient surgeons carried out this many primary blast surgical cases and so analysis was limited to up to 100 cases. Therefore, of the 3136 primary blast cases overall, 1951 cases were identified in the selected group of 40 surgeons, and after mean cases >02:30:00 hours were excluded and also surgeons with >100 cases, 265 blast trauma cases remained, and the mean sequential cases contributed to 24 separate mean operation times for cases 1-100. This data is portrayed sequentially for the case number in the group surgical history where the above criteria were met. See summary output below which shows that the mean operation time for a group of selected surgeons decreased as they carried out sequential primary blast trauma cases (i.e. they got progressively better). Linear regression analysis is statistically significant ($p<0.05$). Sequential blast trauma case number significantly predicts the mean operation time ($p<0.05$). The overall regression model was significant, [$F(1,22) = 10.992$, $p<0.01$, $R^2=0.333$].

Figure 5 Linear regression analysis:

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.57722
R Square	0.333183
Adjusted R Square	0.302873
Standard Error	0.011652
Observations	24

ANOVA

	df	SS	MS	F	Significance F
Regression	1	0.001493	0.001493	10.99255	0.003144
Residual	22	0.002987	0.000136		
Total	23	0.00448			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0.10936	0.007337	14.90497	5.58E-13	0.094144	0.124576	0.094144	0.124576
case number in series	-0.00035	0.000105	-3.3155	0.003144	-0.00057	-0.00013	-0.00057	-0.00013

General Discussion

The database described in this thesis is a catalogue of consecutive surgical cases and surgical procedures performed in one hospital in Afghanistan, 2009-2014 (the end of UK operations). The database is the largest of its kind to come from any modern conflict to date, and the work presented here is the first analysis of the record of surgical cases in the latter half of the conflict.

Previous studies identified the following problems:

- Surgeons surveyed did not feel prepared for the trauma surgery they faced in Afghanistan (Schwab, 2015)
- The surgical skill set of procedures required for war is yet to be defined (Schwab, 2015)
- The opinion that current surgical training does not adequately prepare the military surgeon for conflict (Hoencamp et al., 2014)
- General surgical training did not prepare those who cared for casualties from terror attacks in 2017 (Smith et al., 2017)
- The humanitarian mission of surgery in conflicts is yet to be defined
- The Disease Non-Battle Injury (DNBI) burden of surgery in conflict is yet to be identified

The thesis presented here aims to investigate these problems and provide the evidence to test the hypothesis that current surgical training does not adequately prepare the surgeon for conflict or terror attacks. This was achieved by investigating whether or not there was any "slipping back" in surgical experience between conflicts, and by analysing the effect of surgical experience of managing complex blast trauma casualties on surgical outcomes of case fatality and length of operations. We present a template for surgical procedures for conflict and terror attacks and set out the surgical skill set for war.

The recent rise in terror attacks, and the blasts from explosions which they bring, are likely to remain a feature of our future both in peace-time and war (Smith et al., 2017). In addition, the DNBI and humanitarian mission of surgery will likely feature highly in future conflicts, and we hope that this thesis addresses gaps in our understanding. We anticipate that future armed conflicts may have exaggerated timelines and that surgeons may find themselves with less support further forward in the conflict zone. We therefore anticipate that surgeons may be expected to do more of the full complement of surgery that is yet to be defined (Hoencamp et al., 2014).

Summary of project findings

Our pre-database exercise showed how worthwhile the record could be and set the scene from personal log books of one surgical specialty; namely the role of plastic surgeons in management of modern combat trauma (Chapter 1). This study suggests that doing a comprehensive inventory of all the surgery performed in Afghanistan would be more informative. This lead directly to the introduction to the thesis, which provides the literature review for each chapter this thesis presents, and the overall methodology for the thesis (see Chapters 2 and 3). The prospectively recorded surgical case history throughout 2009-2014 was transcribed into an Excel Spreadsheet (Microsoft 2010) for analysis, and represents the largest surgical database of its kind to ever come from a modern conflict (Chapter 3). The combat activity, the wounding patterns, the surgeons and the mission emphasis of the hospital all changed during the study period. The aims of the thesis we summarise in the thesis outline, and each chapter represents a separate study with different methodologies (see Chapters 2 and 3).

Firstly, through comparison of our findings to previous similar classifications of surgical procedures of the preceding years of the conflict in Afghanistan, we showed that the surgical skill set for war, so far proposed from previous studies is not supported by our findings (Hoencamp et al., 2014; Hoencamp 2016; Jacobs et al., 2012; Parker, 2008; Ramasamy et al., 2010; Schwab, 2015;) (Chapter 4).

We highlighted key similarities and differences to studies that have come before our own (i.e. Parker, 2008; Ramasamy et al., 2010; Jacobs et al., 2012) (Chapter 4). We classified the surgical procedures (n=20,266) in Afghanistan 2009-2014, and then compared this analysis to that from the preceding years of the conflict in Afghanistan. To do this we used similar methodologies to those of previous studies. For example, we used a similar classification of surgical procedures to remain consistent with previous studies and enable comparison of data.

Previous studies suggested that surgeons needed more burns and paediatric training prior to deployment (Jacobs et al., 2012; Ramasamy et al., 2010; Schwab, 2015). Our key findings provide further emphasis: the surgical requirement for key damage control procedures (laparotomies; vascular procedures; application of external fixators and amputations) were significantly higher than previously documented (Chapter 4: Table 1). Vascular surgical procedures were required in 10% of all surgical cases, a 4-fold increase. We also demonstrate that the Disease Non-Battle Injury (DNBI) surgical burden in armed conflict was higher than previously stated and accounted for 14.4% of primary (emergency) surgery in Afghanistan (Chapter 4).

Our findings support those of Schwab (2015) who suggested recently that the comprehensive surgical skill set for war is yet to be determined. Nor has a comprehensive skill set been internationally agreed (Hoencamp et al., 2014). Compared to Ramasamy et al., (2010), largely cited as the definitive classification of surgery carried out in Afghanistan: Chapter 4's initial analysis of the thesis's unique database highlighted significant differences, and the results supported the fact that a surgical skill set for war remains undefined.

The following findings from Chapter 4 have specific implications on future surgical provision in conflict and surgical training:

- 28.5% of all amputations were bilateral. This new finding may have implications for surgical training, and for tourniquet provision to soldiers
- Eye surgery accounted for 2.0% of all procedures (Chapter 4; Table 1). UK troops were not issued with anti-ballistic eye protection until 2011, up until then they were issued with goggles for protection from sand and UV (BBC; 2011).
- Negative Pressure Wound Treatment (NPWT) accounted for 10.7% of procedures and was used in 20% of surgical cases
- Just 22.9% of laparotomies were completed within the recommended 90-minute Damage Control Surgery cut-off (Hirshberg, 1999; Waibel and Rotondo 2010).
- 48.2% of surgeries carried out were secondary cases (Chapter 4: Fig.2).

Considering the differences between our results and those reported by Ramasamy, 2010 and Jacobs et al., 2012, we cannot assume that the classification of surgical procedures presented in 2010 (Ramasamy et al., 2010) of a 2-year period of the conflict in Afghanistan is sufficient to accurately suggest the surgical skill set required for war.

<u>What is the surgical skill set for procedures required for conflict?</u>

There is a significant need to ascertain what procedures were most frequently performed since Porta et al., (2013) presented the results of a survey from surgeons that deployed to Iraq and Afghanistan: 30% of surgeons who responded performed procedures they had not done before.

We anticipate that the surgical requirement for DNBI and Humanitarian injuries is likely to remain consistent in future conflicts. Since DNBI workload was higher than in previous studies, we ascertained which DNBI procedures were used most frequently in order to provide a template for surgical procedures to manage DNBI. We found that 74.7% of DNBI surgery, which accounted for 14.4% of total primary surgery in Afghanistan, was carried out on ISAF casualties

We found that the 5 DNBI surgical procedures most frequently performed in armed conflict were: appendectomy; abscess I&D; bite wound management; testicular torsion / orchidopexy procedures and hernia repair. Surgical management related to sexual health accounted for 1.6% of DNBI surgery, and less than 0.02% of the surgical workload was on female casualties (Chapter 5).

We already showed that secondary (definitive) cases took up almost half the amount of operating time in Afghanistan – likely because civilians were known to be returning to the relatively poor health care system of the host-nation. There have been few studies evaluating the impact of the civilian population on surgical provision. The present study shows that they account for 57% of secondary surgery, and as approximately half of all surgery was secondary, this is a significant and high surgical workload (Chapter 5).

We showed in Chapter 4 that there were significantly fewer civilian cases than previous studies and that combatant casualties increased compared to previous studies (Maitland et al., 2016; Chapter 1). For the first time, we account for humanitarian surgery: it made up 33% of surgical cases and there were significantly more secondary cases on civilians compared to combatants (Chapter 5). Future armed conflict casualty extraction times are likely to increase, and with that an increased requirement to provide secondary surgical provision to all casualties, meaning fewer humanitarian cases receive this level of care. (Chapter 5).

We show that humanitarian surgery was problematic – operations took longer to perform (Chapter 7), and the outcomes were poor because of presumptive pre-morbid conditions as a result of poor local health provision, (and a lack of body armour) (Chapter 5). Humanitarian casualties are more likely to die in armed conflict than combatants (Chapter 5). We show that differences in regions of trauma between casualty nationalities are in spite of blast being the primary mechanism of injury in PAED; CIV; and ISAF/combatant groups.

Our study shows the relationship between casualty nationality and wounding patterns, and suggest a template for humanitarian surgical provision in conflict, which has not been previously shown. Previous studies have shown the multiplicity of wounding caused by blast/explosion, however the present study translates that into where surgery was performed. We present the most frequently performed humanitarian surgical procedures as a suggested template for training for future conflicts (Chapter 5).

The present study shows that civilian casualties had statistically more Abdominal Cavity (AC) surgery compared to ISAF. We found that humanitarian casualties, not wearing body armour, were significantly more likely to die during surgery (1.5%) than the combatant (0.8%) (Chapter 5). A statistically greater amount of trauma surgery to the abdominal cavity occurred in civilian casualties compared to ISAF (Chapter 5: Table 2). There were significantly more torso wall trauma cases on paediatric and civilian casualties than ISAF. Our findings support previous studies that described truncal haemorrhage (thorax, abdomen and pelvis) accounting for the majority of preventable deaths (Eastridge et al., 2012).

Civilians and ISAF are all significantly more likely to have bilateral lower extremity injuries than unilateral. ISAF suffered more bilateral lower extremity injuries than any other demographic. Unilateral upper extremity trauma was more likely in ISAF and civilian casualties than bilateral upper extremity trauma. There was significantly more bilateral lower extremity trauma for ISAF and PAEDs casualties than unilateral lower extremity injuries (Chapter 5; Table 2).

There was no significant difference between right and left upper extremity trauma, hand trauma or buttock trauma between civilian and ISAF casualties. We can clearly show that upper extremity trauma is significantly more likely to be unilateral, and lower extremity trauma is more likely to be bilateral. We suggest that extremity, hand and buttock regions remain vulnerable to blast injury regardless of body armour (Chapter 4).

We found that body armour worn by ISAF was effective. Civilians suffered significantly more abdominal trauma and torso wall injuries than ISAF casualties (Chapter 5). This potentially highlights the effectiveness of Personal Protective Equipment on trauma, however we suggest the following regions remain unprotected for ISAF:

- Perineum: When we compared surgical management between combatant and civilian groups, we found that significantly more of the ISAF casualties suffered perineal injuries compared to CIV or PAEDs casualties. There were significantly more casualties with trauma to unilateral upper extremities compared to bilateral upper extremities in the ISAF population. There was statistically more proximal vascular control surgery needed for the ISAF population compared to civilian (Chapter 5; Table 2).

- Neck: Paediatric cases had significantly less surgical intervention to the junctional area of the neck compared to adults (CIV/ISAF) (Chapter 5; Table 2). Therefore, PPE that shortens the neck – not dissimilar to NFL/motor racing equipment we suggest should be the focus of future development in this area. The neck region was significantly more injured than the axilla, or the groin (Junctional areas) in ISAF and the civilian population (Chapter 5; Table 2). These findings show that despite body armour, the neck region remains particularly vulnerable to trauma.

    - Face: Facial trauma accounted for 15.4% of ISAF trauma surgery. Paediatric facial trauma required more surgical intervention than any other region of paediatric injuries. We also found significantly more paediatric facial trauma cases compared to adult casualties (ISAF and civilian), and the most common region of paediatric trauma was the face (Chapter 5: Table 2). Edwards et al., (2012, 2014) described surgery for head injuries was more common in 4-14yr old group than older patients and we also showed that surgery for head injuries was statistically higher in paediatric casualties. We show that the head, face, eye and burns related surgery typified paediatric injuries.

We report a significant decrease in paediatric cases, as a proportion of the total (Chapter 5: Table 1; 6.1%) compared to 14.7% in Ramasamy et al., 2010. This figure was 5.1% in Iraq (Chapter 5: Table 1) (Ramasamy et al., 2010); and 6% reported by Jacobs et al., (2012) for Paediatric cases in Afghanistan. Paediatric casualties were caused primarily by Blast, accounting for 24.5%; then GSW and burns. There was significantly more head trauma in the paediatric group compared to adult casualties (ISAF and civilian) (Chapter 5: Table 2). There were significantly more paediatric eye trauma cases compared to ISAF (Chapter 5; Table 2).

Regardless of changes in warfare and weapons technology, soldiers will consistently require a similar provision of DNBI surgery as outlined in this study, and civilians will still be embroiled in war.

In summary, Chapter 5 presents the most frequently performed surgical procedures for DNBI, and humanitarian surgery from our most recent conflict, Afghanistan, and suggests the template for DNBI and humanitarian surgery for future conflicts.

Since there were significant differences between our findings in (Chapter 4) and previous classifications of surgery, Chapter 6 was needed to create a new classification of surgery by anatomical region, which for the first-time accounts for the poly-trauma casualty, as well as the surgical impact of the multiplicity of wounding seen in Afghanistan.

The study of the wounding patterns reported in Chapter 5 led us to examine more extensively what surgical procedures were carried out to manage these injuries, and to establish what surgery we did to the following regions: eyes; limbs (including perineum and anorectal region) and junctional zones; and areas of non-compressible haemorrhage (chest, abdomen, axilla, groin, and neck). We therefore established the surgical procedures most used to stop bleeding and preserve eyes, life and limb during the conflict in Afghanistan.

In Chapter 6, we developed a new categorisation of trauma surgical procedures according to anatomical regions. It was based on our analysis of wounding patterns in Chapter 5. We analysed the 10,891 consecutive cases in Afghanistan 2009-2014, and categorised 20,266 procedures by anatomical region (Chapter 6; n=13,909) and in doing so accounted for the poly-trauma nature of casualties. Chapter 4 did not capture this since procedures were counted once per case despite being carried out in some instances on multiple regions of the body in one operation (case), and as such we were able to classify the surgical procedures in the Afghanistan conflict comprehensively.

In chapter 6, we present the impact that wounding has on surgery- this is the first time this has been done in the context of war. We can learn from Afghanistan what surgery was performed most frequently, and on which regions of the body, and assume that similar wounding patterns will be seen again, as have already been seen in the recent terror attacks of 2017. We discussed in Chapter 4 that the classification of surgery by specialty carried out in studies from the preceding years of the conflict is not the whole picture, especially when taking into consideration the differences we highlighted in that Chapter. Therefore, we analysed all the surgical procedures categorised by anatomical region in order to account for the true surgical workload in war.

Firstly, from our analysis of the extremities surgery performed, we found that most of the proximal vascular control procedures to junctional areas were to the groin (26.7%), significantly more than the axilla or neck (Chapter 6; Fig.3). This is perhaps related to the high rates of amputation: 2 amputations per 10 cases. In Chapter 5 we showed significantly greater bilateral lower extremity surgery compared to unilateral, in Chapter 6 we go on to show that Lower limb amputation was significantly greater than upper limb amputation (Chapter 6; Fig.1). As a result, 3.3% of all surgical cases required proximal vascular control, and 23% of proximal vascular control procedures were for Above Knee Amputations (AKA). Explosions cause this wounding pattern and the non-compressible haemorrhage that ensues requires proximal vascular control. We show that the burden of orthopaedic surgery was significantly less than previously recorded (Chapter 6; Table 2). We present the 5 most frequently performed surgical procedures employed to control non-compressible haemorrhage in junctional zones, neck, axilla and groin.

Explosions/blast injuries cause injuries to the perineum. We show for the first time that 57% of cases involved surgery to male genitalia, but only 0.4% resulted in orchidectomy (Chapter 6). We show for the first time the high incidence, and surgical burden, of buttock wounds, and report that 7.4% of cases involved the buttock region and 22.1% of buttock wounds required Negative Pressure Wound Treatment (NPWT) (Chapter 6).

Secondly, we investigated what impact explosive injuries to the perineum, ano-rectal region and extremities had on abdominal surgery. Considering the high rates of lower extremity amputation procedures, we wanted to find out if this had an impact on other surgery. We found that surgeons were significantly more likely to open the abdomen to gain proximal vascular control than they were to open the chest cavity (Chapter 6; Fig.1). Of the proximal vascular control procedures, 45.8% required the abdominal cavity be opened to gain control compared to 30% of proximal vascular control cases involving opening the chest cavity. We looked at more detail into the types of procedures carried out intra-abdominally in more detail and discovered for the first time that significantly more surgery was carried out to the large intestine than the small intestine (Chapter 6). There were 1137 procedures to the intestine alone or 10.4% of cases involved intestine surgical procedure. The second most commonly operated on intra-abdominal organ was the spleen. Again, for the first time we show that there was a significantly greater requirement for intrabdominal surgery than previous studies and itemise the most frequent surgical procedures performed (Chapter 6; Table 2).

Glasgow et al., (2012) reported that rectal/colon trauma increased mortality rates. Out of all the surgical cases in the present study, 1% of all the surgical cases underwent further endoscopic investigation of wounds to the perineum/ano-rectal regions involving sigmoidoscopy and proctoscopy procedures (Chapter 6).

The secondary surgical burden of this abdominal surgery was the abdominal wall and non-closure techniques which we analysed for the first time (Chapter 6). There were 3499 procedures to the abdominal cavity and wall, of which 32% involved surgical intervention to the abdominal wall. Out of the total laparotomy cases 56% of the abdomens were not closed, and these required non-closure techniques: 40.6% of secondary laparotomies required NPWT and 19.7% required partial/temporary closure techniques (packing; mesh; internal closure of fascial layer). The remainder were left open or underwent Delayed Primary Closure (DPC) at later stages (Chapter 6).

Overall 22.4% of all cases required NPWT. We show the 5 most frequent surgical procedures for anorectal region/buttocks and urological trauma in Afghanistan (Chapter 6).

Thirdly we wanted to analyse the head and neck region further as we already know from Chapter 5 showed that the neck suffered more trauma than the axilla and the groin in civilian and ISAF groups. We presented in Chapter 5 a suggested shoulder pad which would "sink the neck", and thus protect it. The shoulder is a close anatomical neighbour to the neck and suffered high rates of injury. Shoulder injuries accounted for 25.2% of upper extremity surgery, and surgical management of shoulder girdle injuries accounted for 22.0% of surgical cases (Chapter 6). The shoulder pad we have suggested above would protect both the shoulder and the neck.

We found no difference between the proportion of neck trauma in ISAF: civilian adults (4%) and is evidence that current body armour does not protect the neck. Breeze et al., (2011) found that 5.2% of cases involved surgery to the face and of those injured service personnel, 33% had facial wounds. We show 3.8% of cases involved surgical intervention to the eyes and in detail, the most frequently performed eye procedures were: washout and irrigation; debridement of eyes; repair of eye lacerations; enucleation and evisceration procedures; and canthotomies (Chapter 6).

In addition, we wanted to analyse in more detail case fatalities, and we found that 9% of casualties that underwent a craniotomy or craniectomy died (Chapter 6). However neurosurgical procedures were infrequent and accounted for significantly fewer procedures than previous studies. We show that this may reflect the effectiveness and adherence to wearing helmets across casualty nationalities.

Lastly, since previous studies showed that there was a low requirement for thoracic operations, in Chapter 6 we analysed the surgery to the thoracic region and we found it to be as high as 8.8% (Chapter 6). We present the top five chest procedures which are: thoracotomy/sternotomy exploration of chest cavity; debridement of multifragment penetrating wounds; resection of lung and repair of lacerations to lung; repair diaphragm lacerations; chest drain insertion (Chapter 6).

The new categorisation of all the surgical procedures performed in Afghanistan by anatomical region enabled us to analyse the impact of the multiplicity of wounding seen in Afghanistan, and in terror-related incidents occurring today, on trauma surgery. We amalgamated the anatomical categorisation of surgical procedures into traditional specialties and found significant differences in the surgical specialty workload when compared to previous accounts (Ramasamy et al., 2010; (Chapter 6: Fig.4; Table 1): significantly more general surgery; head and neck surgery, and significantly less: orthopaedic surgery; neurosurgery and burns related surgery was carried out (Fig. 5; Table 2).

We compare the findings of the present study (Table 4) with the previously suggested surgical skill set for war (Ramasamy et al., 2010; Hoencamp et al., 2014) to ascertain the evidence base for this proposal. We found that some of the procedures suggested occurred at very low rates, whilst others that we found to be a significant proportion of surgical workload in the present study were not represented at all (see Chapter 6: Table 4).

We hope this study will provide the evidence previously not available to enable the military and government to prioritise what key skills are essential for any surgeon in future conflicts, regardless of surgical background. We compared the results of the present study and highlighted differences to the recent discussion held by the Committee of Chiefs of Military Medical Services, COMEDS, on a possible NATO curriculum (Chapter 6: Table 3). The discrepancies, or gaps, we highlight can help implement much needed standardisation for NATO surgeons, and inform civilian training practices by presenting the most frequent surgical procedures by body region to account for the polytrauma caused by explosions (Chapter 6: Fig.4; Table 1; Table 3).

Future conflicts may not have the surgical provisions found in Afghanistan at Camp Bastion's Trauma Centre. This study has itemised the surgical procedures carried out from 2009-2014, and in so doing provides the much-needed evidence for the effective training of surgeons in surgical procedures required for future conflicts.

The findings of the present study may be incorporated into the management of the emergency surgical patient within the civilian practice to deal with terrorist attacks, mass casualty events and or catastrophes in times of peace and war.

Our study's approach to analysis of surgical interventions by anatomical region was unique. Our analysis enabled us to: account for the polytrauma nature of injuries caused by blast/explosion in Afghanistan, identify the regions of the body that underwent the most surgical interventions; and identify what those surgical interventions were. The main findings of this study help to highlight specialist regions and surgical procedures which are paramount to reduce preventable death.

The findings of our thesis so far support the fact that the surgical procedural skill set requirement for conflict/combat zones/war has yet to be defined. This is evidenced by the significant differences between our thesis findings in Chapters 4, 5, and 6 compared to previous classifications of surgery in Afghanistan.

In Chapter 7, we move on to address the fact that presently there is no internationally agreed surgical skill set for war (Schwab 2015). As blast injuries become more prevalent in peacetime, the surgical procedures outlined in the present study are no longer confined to the military or armed conflicts overseas. We provide the first evidence-based surgical template for procedures that may improve readiness and standardisation for terror attacks and armed conflicts. We also established that surgical experience influenced measurable outcomes such as case fatality or length of operation.

The methodology in this study was distinct because we presented the most frequently performed surgical procedures into a template schematic based on the anatomical categorisation in Chapter 6. This template provides the comprehensive skill set for future surgery in war and terror attacks. We also selected the most severely injured cases and analysed the surgeons involved in their care. We separated the surgeons into two groups based on their experience of surgically managing blast trauma during the conflict in order to ascertain if there was any difference between the two groups' case fatality rates. We also analysed as a group, the average length of operation time sequentially as each surgeons' case number increased.

Despite advances in Combat Casualty Care (CCC) and the decrease in lethality of wounding over time, we discovered that there is a "slipping back" in surgical skills which affects mortality between conflicts and took the first half of the conflict in Afghanistan to correct itself. We found the percentage of casualties who Died Of Wounds (DOW) having reached a surgical treatment facility, was significantly higher at the start of the conflict in Afghanistan compared to the end of the conflict in Vietnam, and we found a significant reduction in DOW rates at the end of the conflict compared to the start (Chapter 7: Fig.1a; Fig.1b; Fig.1c; Table 1). We found this despite a decrease in lethality of wounding and advances in Combat Casualty Care (Gawande, 2004; Owens et al., 2008; Belmont 2012).

This reduction in case fatality has been noted before in other studies, however, the reasons have remained unanswered (Gawande, 2004). We explored further to see whether the rise in case fatality could be due to a slipping back in surgical experience between conflicts, whereby the skills ascertained whilst deployed, were not cultivated in training during peace-time and the experience was lost, resulting in higher death rates at the start of the conflict in Afghanistan which lasted the first half and only started to improve in the second.

We show that groups of surgeons who carried out more than 50 damage control primary blast surgical cases during their deployment to Afghanistan had reduced case fatality rates compared to those surgeons involved in less than 50 blast trauma cases (Chapter 7; Fig.3) and we show that the average operation length reduced as the surgeons' case number (and hence experience) increased (Chapter 7; Fig. 5).

We built on the analysis in Chapter 6 and the new categorisation of surgery by anatomical region to present the template for surgical procedures for conflict and terror attacks. We discovered for the first time an evidence-based skill set requirement for war. We present the top ten most frequently carried out surgical procedures by anatomical region.

We discovered that casualty demographics influenced primary BI surgery operation time, with local national (PAED; EF; CIV; ANSF) cases accounting for majority of cases more than 01:30:00 hours (47.4%) compared to ISAF (31.3%) (Chapter 7; Table 2). Significantly more cases (operations) on ISAF casualties were less than 01:30:00 hours compared to more than

01:30:00 hours (Chapter 7; Table 2). We also show that secondary (definitive) surgery was close to 50% of the surgical workload, and 57% of that was on civilian population (Chapter 4). This may have an impact on surgical provision and planning in future combat zones as the humanitarian surgical provision may be greater due to the potential for conflict zones in the future taking place in more built up urban areas, and the likelihood of refugees.

Previously, it has not been accepted that there is an initial learning curve with commensurate loss of life when surgeons arrive in a conflict zone (Ramasamy et al., 2010). We have shown for the first time that surgical outcomes improved with increased surgical experience. We show that there is a learning curve when surgeons arrive in a conflict zone and that there is a rise in preventable deaths at the start of armed conflicts, primarily because new surgeons have less blast trauma experience (Chapter 4; Chapter 7). "Slipping back" in surgical experience between armed conflicts could lead to increased case fatalities and prolonged surgical times in future armed conflicts. We anticipate that there may be a similar rise in case fatality at the start of the next armed conflict, potentially because of the loss in surgical experience.

Therefore, we must also accept that there will be preventable deaths in future terror attacks, mass casualty events and armed conflicts unless this is corrected.

Our analysis supports the hypothesis that surgical training does not adequately prepare the surgeon for the injuries sustained in armed conflict, specifically blast/explosive trauma.

As a result of the findings of our study, we suggest a dedicated Complex Attack Surgical Team (CAST) should be set up in the UK. CAST will be made up of surgeons with experience of more than 50 primary (emergency Damage Control) blast trauma case experience, who will be ready, and able, to go to the site of any terror attack (explosion/blast/bombing), mass casualty event, and will carry out the primary blast damage control surgery at the host trauma centre, or local hospital. This initiative could reduce the incidence of preventable deaths.

Chapter 7 developed a template for surgical procedures (based on the findings of the thesis), required for future armed conflicts and terror attacks. We hope that the template may be used by NATO to inform their proposed introduction of a NATO surgery standard (Chapter 6) (Hoencamp et al., 2014). We hope that this template gains consensus to form the definitive surgical skill set for war. We hope the template is applicable to future conflicts, and we hope it helps the military to decide which surgeons are most qualified to deploy based on risk, to prioritise the surgical procedures required.

The limitations of the thesis

The thesis is an analysis of a past conflict, and it is possible that future conflicts will have different medical support compared to the Camp Bastion facility.
However, we believe that the proposed evidenced-based template for surgical procedures could serve as a minimum standard of surgical procedures that surgeons should be competent in, as a team, and may be used as the skill set requirement for future armed conflicts.

Despite some recording deficiencies in the log-books, such as partial demographic details, or regions of surgery, because of the size of the database and our novel categorisation of surgical procedures by anatomical region, we were able to account for the poly-trauma nature of blast/explosion injuries. Thus, we present the most comprehensive analysis yet of any modern conflict.
The intent for Damage Control (DC) for each case was not documented in the log-books and therefore the database. Therefore, we were unable to analyse what proportion, of say DC laparotomies, were managed appropriately to their intent. However, the primary blast cases that required damage control laparotomies to gain proximal vascular control enabled us to select for this group and lead to a more detailed analysis of the surgeons involved in these more severely injured cases, and their outcomes. Not having the nationality available of every casualty, or the gender of civilian cases, restricted analysis of the impact trauma surgery on female casualties.
Individual surgeons, in the group of 40 selected for their involvement in the most severely injured blast trauma casualties operated in different teams for different cases, and the impact of human factors such as team dynamics, etc., fell outside the scope of the present research, but may have had an impact on surgical outcomes.

Contribution of thesis

Where do we stand currently with surgical trauma training?

The Intercollegiate Surgical Curriculum Programme (ISCP) recognises that additional competencies are required for adult and paediatric general surgery to treat major trauma. The latest syllabus of the ISCP sets apart general surgeons with an ‘Advanced Trauma’ interest e.g. those who work within a Major Trauma Centres (MTC), or military surgeons (currently a recognised subspecialty of general surgery in the UK) (Ramasamy et al., 2010; Smith et al., 2017; ISCP 2013).

The ISCP syllabus expects that by the level of consultant, general surgeons are competent to perform DC thoracotomy, laparotomy and initial surgical management of head and neck, vascular and urogenital injuries in adult and paediatric patient (ISCP 2013; Smith et al., 2017). The detail, however, of competencies goes no further, since they are yet to be determined.

In relation to paediatric trauma surgery, the syllabus mentions the ability to perform a trauma laparotomy and thoracotomy to the level of ‘can do whole but may need assistance’ and ‘can do with assistance.’

The syllabus does not specify the need for advanced paediatric trauma surgeons with a more comprehensive skill set or what those surgical procedural competencies should be (ISCP 2013).

There are courses such as the Definitive Surgical Trauma Care (DSTC; live-animal training) and the Definitive Surgical Trauma Skills (DSTS; cadaveric training, originally designed for the military surgeon in 2002) to gain further skills, but these courses are not current requirements. A third of general surgical consultants on call in UK MTCs have not completed one of these courses (Garner, 2014; NHS England National Peer Review Programme, 2014).

Trauma surgical training remains a low priority in the UK given the general perceived lack of trauma that requires such surgical intervention.

There is a lack of standardisation of what the surgical procedures required to manage major trauma in adult and paediatric casualties is, or should be.

Despite the above, the initiative by NHS England to standardise trauma care in the UK has so far led to the introduction of a fellowship in trauma available in 2018 for general and vascular surgeons in resuscitative surgery, and the other doctors (not surgeon specific) to become major trauma consultants (Smith et al., 2017). Guidelines are currently being developed for the assessment, and initial management, of major trauma with a focus on resuscitative and damage control surgery (Glen et al., 2016). NHS England describes that the Manchester Arena Attack generated 350 hours the week following the attack and is recognised as a lesson in planning (Moran et al., 2017).

This thesis:
We present important findings that can, and do, relate to the current civilian surgical training practices and provision of trauma surgery in the event of future terror attacks, and armed conflicts.

We contribute the following original research findings, which address the aims of the thesis:

- There are significant differences in the classification of surgery we found compared to previous studies (Ramasamy et al., 2010; Jacobs et al., 2012) (Chapter 4; Chapter 6). These findings support previous suggestion that the surgical skill set for war does not currently exist (Schwab, 2015).
- The mortality between conflicts, and the mortality was highest at the first half of the Afghanistan conflict compared to the end of our previous conflict in Vietnam despite advances in CCC and decrease in lethality of wounding over time (Chapter 4)
- We show that this may correlate to a "slipping back" in surgical experience since we show that case fatality and average operation length for primary blast damage control cases was significantly reduced with increased blast surgical experience (Chapter 7)
- We anticipate that there may be a similar rise in case fatality at the start of the next armed conflict, as the surgical experience gained in Afghanistan slips away. This pertains to the recent surge in terror attacks in 2017, where surgical teams that were unfamiliar with blast trauma were operating. The findings of our thesis support others reporting that surgeons felt under prepared for conflict, and for terror attacks (Hoencamp et al., 2014; Moran et al., 2017; Schwab, 2015; Smith et al., 2017) (Chapter 7).
- We anticipate, unless corrected, that this loss in and lack of blast trauma surgical experience may lead to further preventable deaths in the future, where in the management of terror attacks by blast naïve surgeons, or in future conflicts.
- It has been previously denied that there is a learning curve when surgeons arrive in conflict zones and an associated rise in preventable loss of life (Ramasamy et al., 2010). We found that reduced blast trauma experience leads to increased operation times and case fatalities (Chapter 7). Therefore, we must acknowledge that the team instruction and surgical training, as it stands, does not adequately prepare the surgeon for blast trauma seen in conflict and terror attacks

- We present a new classification of surgery by anatomical region which accounts for the poly-trauma casualty and the surgical impact of the multiplicity of wounding seen in Afghanistan (Chapter 6)
- In doing so, we present the most frequently performed surgical procedures in conflict categorised by the anatomical region that they were most frequently performed on (Chapter 6)
- We amalgamated the itemisation of surgical procedures performed into traditional surgical specialties to compare to previous studies and ascertained the true surgical workload to aid future planning of surgical provision in combat zones (Ramasamy et al., 2010; Hoencamp et al., 2014) (Chapter 6)
- We compared the results of the present study, and highlighted differences, to the recent discussion held by the Committee of Chiefs of Military Medical Services, COMEDS, on a possible NATO curriculum (Chapter 6: Table 3). The discrepancies, or gaps highlighted, we hope, will help implement much needed standardisation for NATO surgeons, and inform civilian training practices
- We show the most frequently performed DNBI surgical procedures in armed conflict (Chapter 5)
- We show the most frequently performed humanitarian surgical procedures and outline the impact of the humanitarian mission of surgery on the skill set required in conflict zones (Chapter 5)
- We present for the first time, the first evidenced-based skill set requirement for war: the template for surgical procedures in conflict and terror attacks (Chapter 7).

The findings support the hypothesis that modern surgical training does not adequately prepare the surgeon for conflict.

Clinical impact:

This study is significant because we present a new methodology to analyse surgical procedures carried out in conflict, firstly through analysis of primary and secondary cases, and secondly through categorisation by anatomical region.

We accounted for the first time, the poly-trauma nature of casualties that have suffered explosive, blast injuries. In doing so, we present the first evidence-based template for surgical procedures for armed conflicts and terror attacks (Chapter 7).

We hope that the template for surgical procedures in future armed conflict and terror attacks, will improve preparedness as the evidence-based set of competencies it presents may lead to standardisation of the skill set requirement for the trauma surgical team in the event of major incidents or terror attacks in the UK.

We propose that surgeons currently practicing in the UK and NATO countries, who have the requisite surgical experience managing ballistic and explosive injuries in adult and paediatric casualties (surgical experience of more than 50 primary DC blast trauma cases), should be recruited to a specialist Complex Attack Preparedness Team (CAST). This team should be able to be activated and mobilised to the site of a terror attack at a moment's notice to support the Major Trauma Centre (MTC) and / or hospital facility to manage the DC surgery in the initial stages.

In addition, we hope that the template presented facilitates the introduction of a NATO curriculum for the minimum skill set for military surgeons, but we recognise that individual NATO countries may wish to implement the possible standard skill set in their own way.

We recognise it may not be feasible for individual surgeons to be able to perform the full complement of procedures in our template, and we emphasise our recommendation that this should, rather be used as a surgical team template.

<u>Future research</u>

1. Standardisation of trauma surgical care: to inform the introduction of a NATO Military surgery standard for the minimum surgical competencies in war; build international consensus on the template for surgical procedures required for conflict, and bring about an international surgical standard for trauma surgery; develop standardisation of civilian surgical training programme for terror attack preparedness; and to enable the

development of a more generalist approach to trauma surgery through the anatomical approach to trauma surgery.

2. The template for surgical procedures details the competencies required of surgeons in future armed conflicts and we hope this will be used by military planners to make an evidenced based, risk-assessed decision as to exactly what combination of surgical competencies and experience is required.
3. The development of a trauma surgery registry made up of surgeons who have blast trauma surgical experience of >50 cases to make up a Complex Attack Surgical Team (CAST) to be deployed to the site of terror attacks, mass casualty incidents, in order to perform life-saving Damage Control surgery and to support the local hospital team thereafter with the secondary surgery. It is our hope that a suitable quantity of adequately trained surgeons be organised and consolidated to respond to terror attacks, not dissimilar to a bomb disposal or Chemical Biological and Radiological and Nuclear team.

Conclusion

This thesis is a comprehensive analysis of the most thorough surgical database ever created in armed conflict and, as such, it provides many valuable lessons to both medical and military professionals. We have defined here for the first time, the surgical competencies for war. We recognise that trauma is still, thankfully rare in the UK and other NATO countries, and that it may not be practicable for all general or vascular surgical trainees to be trained in the areas of surgery our template presents, however it is our hope that a suitable quantity of adequately trained surgeons be organised and consolidated to respond to terror attacks, not dissimilar a bomb disposal or Chemical Biological and Radiological and Nuclear (CBRN) team experts.

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Appendix

Appendix 1: Publications (see Chapter 1):

See Chapter 1: Maitland, L, Lawton, G, Baden, J, Cubison, T, Rickard, R, Kay, A, and Hettiaratchy, S. (2016) The Role of Military Plastic Surgeons in the Management of Modern Combat Trauma: An Analysis of 645 Cases. *Plast Reconstr Surg.* **137**(4), pp.717-724.

The Role of Military Plastic Surgeons in the Management of Modern Combat Trauma: An Analysis of 645 Cases

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Background: Plastic surgery has historically been linked to war. Between 2008 and the end of combat operations in Afghanistan in 2014, British military plastic surgeons formed part of the multinational military surgical team at the Role 3 Medical Treatment Facility, Camp Bastion, Helmand Province. The present study aimed to analyze the activity of these surgeons objectively and to determine the utility of their deployment.

Methods: Data were gathered prospectively from four periods (2009 to 2012). This coincided with different surgeons, types of combat activity, wounding patterns, and mission emphases for the hospital. Various metrics were employed.

Results: Plastic surgeons were involved in 40 percent of surgical cases (645 of 1654). This was consistent, despite changes in the predominant wounding mechanism and casualty population. One-third of cases involved the plastic surgeon as the lead or sole surgeon and two-thirds involved working with surgeons from other disciplines. Caseload by anatomical region was as follows: hand and upper limb, 64 percent; head and neck, 46 percent; lower limb, 40 percent; and trunk, 25 percent. A median of 1.75 body areas were operated on per patient. Involvement did not differ between patients wearing combat body armor when injured and those who were not.

Conclusions: Plastic surgeons played a significant role in the management of modern military trauma. This reflects the types of injuries sustained and the expertise of military plastic surgeons complementing the skill set of the other surgical team members. The level of activity was independent of wounding patterns, suggesting that the specialty may be useful, irrespective of the nature of the conflict. (*Plast. Reconstr. Surg.* 137: 717e, 2016.)

U.K., U.S., and coalition forces deployed to southern Afghanistan at various time points after 2006. Injury patterns changed over the course of this conflict with the increased use of improvised explosive devices.[1] Changes to personal protective equipment and improvements in field care and medical evacuation have led to an increase in the numbers of casualties surviving but also to an increase in extremity injuries and amputations.[2–5] In response to these events, from 2008, the makeup of the multinational surgical teams deployed to the Medical Treatment Facility at Camp Bastion, southern Helmand Province, was adapted to include British plastic surgeons, complementing the traditional team of an orthopedic surgeon and a general surgeon (vascular or colorectal surgeon).[3] This is in contrast to previous conflicts where plastic surgeons were only involved later in the evacuation chain.

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A "Hot Topic Video" by Editor-in-Chief Rod J. Rohrich, M.D., accompanies this article. Go to PRSJournal.com and click on "Plastic Surgery Hot Topics" in the "Videos" tab to watch. On the iPad, tap on the Hot Topics icon.

The main drive for the deployment of plastic surgeons to Afghanistan was the increase in the incidence of multiple, complex extremity injuries being sustained. These injuries are challenging to manage and require a multidisciplinary approach.[6] It is essential that, alongside saving life, a focus is maintained on maximizing the outcome for each individual limb, so that the patient with multiple limb injuries can achieve the best functional result. This requires that subject matter experts for the different elements of limb salvage (i.e., plastic and orthopedic surgeons) are present from the first surgical intervention. Although the paradigm used on combat operations is that primary amputations are not carried out on coalition forces, this multidisciplinary team can decide whether good long-term function is best achieved by limb salvage and reconstruction or whether amputation and prosthetic rehabilitation would be the better option. Such decisions must be achieved within the time constraints of damage control surgery and multiple casualty scenarios; thus, there is a need to have key decision-makers present from the outset.[5,7]

This study aims to examine the activity of the plastic surgeon in this scenario. The period studied (2009 to 2012) coincided with the busiest period of combat for coalition forces, and the highest casualty rates. The domains examined were as follows: how much operative work the deployed plastic surgeons performed and which plastic surgical procedures were most used. Collaboration within the surgical team was also studied. During the period of the study, various aspects of combat operations and the consequent casualties changed. The consistency of the involvement of the plastic surgeons despite these changes in injury patterns and type of combat operation was important to ascertain, to determine the external validity of experience in this conflict for future combat operations.

PATIENTS AND METHODS

Patient Identification

A comprehensive analysis of prospectively collected operation logbooks, covering five tours of duty of between 6 and 8 weeks each, was performed to identify all operations carried out by plastic surgeons in the Role 3 Medical Treatment Facility in Camp Bastion. The data covered during four separate periods between May of 2009 and August of 2012 (cohorts A through D). Operations that did not involve a plastic surgeon were excluded.

Data Set Collected

Four domains of data were collected, as follows.

Plastic Surgical Activity

This was collected as the percentage of surgical operations performed by the deployed plastic surgeon, against a denominator of all surgical cases. Whether the plastic surgeon operated alone or with other surgeons was determined.

Body Regions

The body regions operated on were determined, and the total number of body areas treated per patient were analyzed.

Nationality of Casualties and the Use of Body Armor

The origin of the casualties was determined by nationality. These data were used as a proxy to examine any difference in surgical activity for a population that was wearing protective body armor (coalition forces) and those who did not wear body armor (Afghan forces and local nationals). In addition, these data analyzed the surgical activity when different types of casualties were being treated (i.e., was the requirement for plastic surgery greater when coalition forces made up most of the casualties or when local nationals were the bulk of the patients treated?). This would have implications for future team planning depending on the type of casualties expected for a particular mission.

Type of Plastic Surgery Activity

The types of procedures performed by the plastic surgeons were determined. This would help identify the skill set required of the team. Procedures were categories into débridement (i.e., wound débridements and explorations), salvage (i.e., revascularization and bone stabilization), and reconstruction (i.e., skin grafting, use of flaps, nerve repair/reconstruction).

Statistical Analysis

Analysis of the data used the Pearson chi-square test, as appropriate, for nominal data. A value of $p < 0.05$ was considered statistically significant. Statistical analyses were performed using IBM SPSS Version 20.0 for Windows (IBM Corp., Armonk, N.Y.).

RESULTS

Data from five tours of duty were captured over four separate periods (cohorts A through D). Surgical cases that involved plastic surgeons were

Table 1. Activity of the Plastic Surgeons*

	Cohort A†	Cohort B‡	Cohort C§	Cohort D‖	Total
Total no. of surgical cases overall	307	412	562	373	1654
Total no. of cases involving plastic surgeons (% of total surgical cases)	131 (43)	178 (43)	199 (35)	137 (37)	645 (40)
No. of plastic surgeons alone (% of total cases)	20 (7)	46 (11)	84 (15)	61 (16)	211 (13)
No. of plastic surgeons as part of the multisurgeon approach (% of total cases)	111 (36)	132 (32)	115 (20)	105 (28)	463 (28)

*Plastic cases performed by plastic surgeons alone vs. multisurgeon team were calculated as percentages of total surgical cases for each cohort overall.
†May 18, 2009, to July 10, 2009; one plastic surgeon.
‡December 24, 2010, to February 19, 2011; one plastic surgeon.
§February 19, 2011, to April 18, 2011; two plastic surgeons.
‖July 13, 2012, to August 23, 2012; two plastic surgeons.

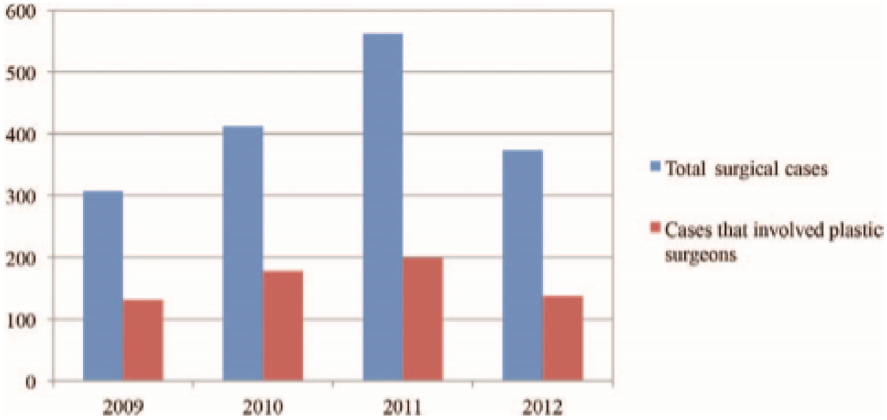

Fig. 1. Proportion of total surgical cases that involved plastic surgeons per time cohort [A through D, 2009 through 2012; total cases involving plastic surgeons (n = 645); total surgical cases [n = 1654 (40 percent)].

selected from between May 18, 2009, and August 23, 2012. In total, 1654 surgical logbook cases were reviewed, of which 645 cases were identified as appropriate and analyzed (Table 1).

Plastic Surgical Provision

There was a singleton plastic surgeon throughout the deployments. They were on call and available 24 hours per day, 7 days per week. All deployed surgeons had completed U.K. residency including subspecialty fellowship training (hand and extremity (n = 2), sarcoma and lower limb (n = 1), head and neck/lower limb (n = 1), and burns (n = 2). Three of the surgeons had completed residency within 6 months of their first deployment, but this involved 8 years of minimum specialist training and 4 years of other surgical training. The other three surgeons had been consultants for 2 to 10 years. Five of the six plastic surgeons underwent the Military Operational Surgical Training course predeployment training.

Plastic Surgical Activity

Overall, plastic surgeons were involved in 40 percent of all surgical cases. This was consistent throughout the study period. One-third of the plastic surgery cases involved the plastic surgeon operating alone or as the lead (13 percent of all surgical cases). Two-thirds involved working with other surgeons (28 percent of all surgical cases) (Fig. 1 and Table 1). Almost half of plastic surgery activity was orthoplastic throughout the study period (Fig. 2). One-third of the plastic surgery activity was with the complete surgical team (general, plastic, and orthopedic).

Body Regions Operated On

Sixty-four percent of cases involved the upper limb (Table 2). Of these, 28 percent were hand injuries and 36 percent were more proximal. Forty percent involved the lower limb. Fifty-eight percent involved the head and neck, which included 32 percent involving the face/head scalp and 5 percent involving the neck and retropharynx.

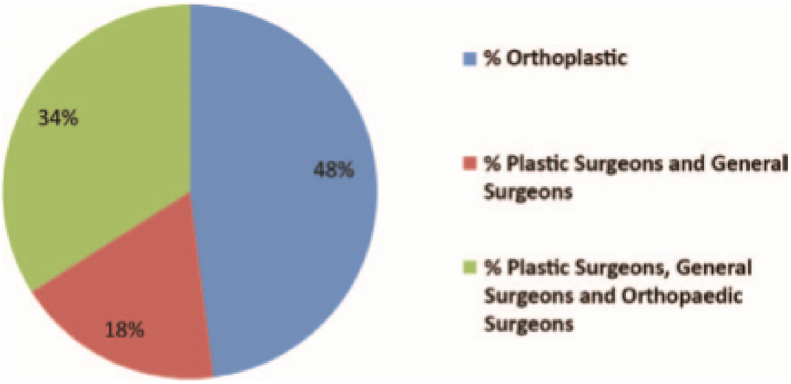

Fig. 2. Other surgeons alongside whom plastic surgeons operated within the multidisciplinary team from 2009 to 2012, overall as a percentage of all cases involving plastic surgeons (Table 1) ($n = 463$). Percentages are expressed as a proportion of total cases involving plastic surgeons ($n = 463$), total orthoplastic ($n = 223$), total plastic and general surgeons ($n = 84$), and plastic general and orthopedic ($n = 156$) (Table 2).

Table 2. Regions of the Body That Plastic Surgeons Operated On*

	Cohort A† (%)	Cohort B‡ (%)	Cohort C§ (%)	Cohort D‖ (%)	Total (%)
Total no. of trauma cases overall	307	412	562	373	1654
Total no. of cases involving plastic surgeons	131	178	199	137	645
Total no. of body regions operated on overall	264	309	344	214	1131
Ratio of trama regions per case¶	2.01	1.73	1.72	1.56	1.75
Total head and neck cases	76 (58)	75 (42)	92 (46)	55 (40)	298 (46)
Head: face, scalp, head, ear	52 (40)	61 (34)	58 (29)	36 (26)	207 (32)
Eyes	7 (5)	7 (4)	28 (14)	15 (11)	57 (9)
Neck and retropharynx	17 (13)	7 (4)	6 (3)	4 (3)	34 (5)
Total upper extremity cases	84 (64)	129 (72)	127 (64)	70 (51)	410 (64)
Upper limb, shoulder	49 (37)	74 (42)	62 (31)	44 (32)	229 (36)
Hand	35 (27)	55 (31)	65 (33)	26 (19)	181 (28)
Total trunk cases	41 (31)	34 (19)	45 (23)	42 (31)	162 (25)
Torso, thorax, back	12 (9)	9 (5)	15 (8)	12 (9)	48 (7)
Abdomen	19 (15)	12 (7)	25 (13)	19(14)	75 (12)
Pelvis	2 (2)	3 (2)	1 (1)	1 (1)	7 (1)
Perineum, buttock	8 (6)	10 (6)	4 (2)	10 (7)	32 (5)
Total lower extremity cases					
Lower limb, hip, groin	63 (48)	71 (40)	80 (40)	47 (34)	261 (40)

*Total cases per region were calculated as a percentage of total surgical cases involving plastic surgeons.
†May 18, 2009, to July 10, 2009; one plastic surgeon.
‡December 24, 2010, to February 19, 2011; one plastic surgeon.
§February 19, 2011, to April 18, 2011; two plastic surgeons.
‖July 13, 2012, to August 23, 2012; two plastic surgeons.
¶Operative trauma regions per plastic case as calculated for each cohort as the total operative regions per cohort/total plastic cases per cohort and overall (total).

Nine percent involved traumatic injury to the eyes. Twenty-five percent of plastic surgical cases involved the trunk, of which 12 percent were injuries to the abdomen, 7 percent were injuries to the chest/back, and 5 percent were injuries to the buttocks and perineum. None of the variations in the percentage of body areas involved over the study period reach statistical significance.

Plastic surgeons on average operated on 1.75 body regions of trauma per case (Table 2). Overall, the regions of the body plastic surgeons operated on remained consistent throughout 2009 to 2012 (Table 2).

Nationality of the Casualties and Use of Body Armor

International Security Assistance Force/coalition forces accounted for 41 percent and Afghan National Security Forces accounted for 20 percent of plastic surgery cases (Fig. 3). Civilians

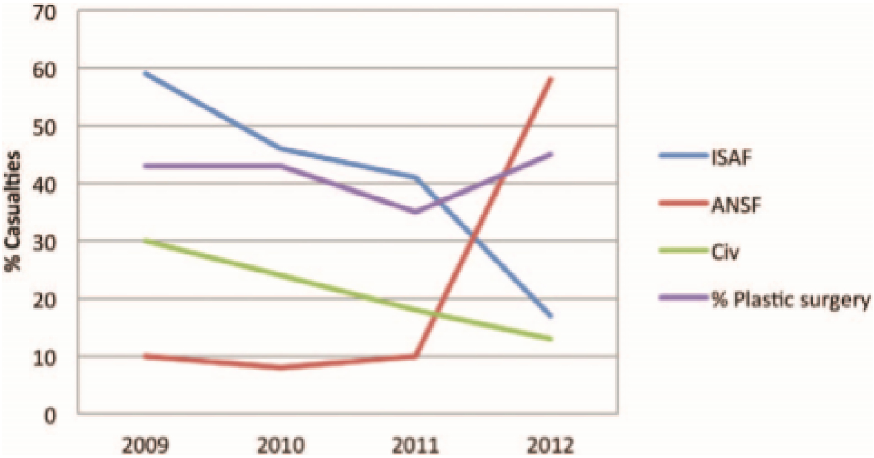

Fig. 3. Relationship between casualty nationality and plastic surgical activity (2009 to 2012). Percentage of plastic cases of International Security Assistance Force (*ISAF*), Afghan National Security Forces (*ANSF*), and civilian (*Civ*) nationality as a percentage of plastic surgical cases versus time (2009 to 2012) alongside activity of plastic surgeons (percentage of total cases that involved plastic surgery from 2009 to 2012 (Table 1).

accounted for the remainder. When nationality of causalities was compared between cohort A (International Security Assistance Force, $n = 77$; Afghan National Security Forces, $n = 13$) and cohort D (International Security Assistance Force, $n = 23$; Afghan National Security Forces, $n = 79$; $p = 0.000$) from 2009 to 2012, respectively, there was a statistically significant decrease in the number of International Security Assistance Force casualties and a reciprocal rise in Afghan National Security Forces casualties (Fig. 3). Civilian casualties accounted for one-third of cases that involved plastic surgeons (Fig. 3), including local national, contractor, interpreter ($n = 136$); and pediatric local national casualties ($n = 78$) [$n = 214$ of 645 (33 percent)]. The plastic surgical activity remained constant despite variations in casualty nationality and the consequent change between a population wearing protective body armor (coalition and Afghan National Security Forces) and a nonprotected group (civilians) (Fig. 3).

Type of Plastic Surgery Activity

Plastic surgery procedures were categorized into débridement, salvage. or reconstruction. The proportion of reconstruction procedures increased from 6 percent in 2009, to 13 percent in 2012, although this did not reach statistical significance (Fig. 4 and Table 3). The débridement activity remained relatively constant at approximately 72 percent (range, 63 to 77 percent). Salvage procedures stayed at approximately 10 percent (range, 9 to 11 percent) (Table 3).

DISCUSSION

The modern specialty of plastic surgery was largely born of developments in the treatment of injuries sustained during World War I. This study shows that the need for plastic surgeons on a modern battlefield is great, with 40 percent of all surgical cases in the Afghanistan field hospital involving the plastic surgeon. The majority of these cases were extremity injuries, and this is a reflection of the wounding patterns being sustained during this conflict. The signature wounding mechanism of the conflict in Afghanistan was the improvised explosive device blast. This led to bilateral lower limb amputations, upper limb fragmentation injuries or amputations, and fragmentation to the face and neck.[8] In previous conflicts, this severity of injury was not as survivable. In this recent conflict, advances in prehospital and acute care mean that these individuals are surviving with one to four severely injured or traumatically amputated limbs. For these servicemembers, survival is not enough; they need to return to high levels of function to achieve a meaningful quality of life. In this scenario, it is essential that the maximum functional outcome is achieved for each injured limb.

The first decision in the management of a severely injured limb is often the most important

Fig. 4. Type of plastic surgical activity. Percentage of total plastic surgery cases per year cohort for débridement and exploration, salvage (revascularization and bony stabilization), reconstruction (split skin graft, flap, nerve reconstruction), and hand.

and is made in the acute setting. This decision must be made by the full complement of surgeons required for limb salvage (plastic, orthopedic, and vascular) so that all options are considered. This facilitates more rapid management planning and leads to better outcomes.[9] The current U.K. military doctrine is that primary amputations are not performed in coalition forces in the deployed setting at the index procedure. Definitive surgery is delayed to facilitate patient involvement in the decision further down the evacuation chain. Amputations were only carried out on nonviable limbs with no reconstructive potential as part of the initial débridement of necrotic tissue.

The types of injuries where a plastic surgeon was involved, though mainly extremity, also involved a high proportion of head and neck cases, and a smaller number of other body regions. This demonstrates the breadth of specialist expertise required of a military plastic surgeon. In the mix of general, orthopedic, and plastic surgeons in the military team, it is possible that the only surgeon with experience with surgical access to the neck is the plastic surgeon. The team is reliant on the plastic surgeon to manage injuries to these areas, including areas that are outside the normal scope of plastic surgical practice, such as ocular injuries. This is reflected by the finding that plastic surgeons operated on a median of 1.75 body regions per patient. Such practice is reflective of the constraints on the size of the team, as it is not possible to have every specialty present in the field hospital. To mitigate this, military plastic surgeons underwent additional training in certain disciplines (e.g., ophthalmology) so that they could deliver a greater level of expertise. In addition to bringing expertise in different body areas, the plastic surgeon also brings specialist skills, such as the management of complex wounds (débridement and exploration), salvage (vascular repair and bony stabilization), and reconstruction (skin grafting and the use of flaps, and nerve repair). All of these used in the appropriate setting can improve patient outcomes and shorten the time these patients spend in the hospital. Microsurgical reconstruction was not used because of operational constraints of time and equipment.

In the deployed setting, the plastic surgeon was twice as likely to be working as part of a multidisciplinary team as to be working alone. Again, this is reflective of the nature of the injuries sustained. These patients had most often sustained multiple injuries to different body regions, and thus surgeons often operated simultaneously for expediency. The most common combination was a plastic surgeon together with an orthopedic surgeon, as would be expected given the high incidence of extremity trauma.

The plastic surgical activity remained consistent despite the majority of casualties changing from International Security Assistance Force/coalition troops in 2009 to Afghan National Security Forces/local nationals in 2012. This is important, as the two different groups represent a population with access to body armor and a population who did not use it. It had been thought that body armor, because it protects the trunk and head, may have led to disproportionately more extremity injuries. In this scenario, one would have predicted a greater need for extremity surgeons (orthopedic and plastic) rather than trunk surgeons (general). In a population without body armor, this situation may have been reversed, because the trunk would be unprotected and vulnerable to injury. The current study suggests that this may not be the case, as both the need for plastic surgeons and the percentage of extremity operations was the same for both the body-armored and non–body-armored groups. It is not immediately clear why this was, but it may have

Table 3. Relationship between Fall in International Security Assistance Force Casualty Numbers and Number of Reconstruction Procedures Being Performed from 2009 to 2012*

Year	Total Plastic Surgery Cases	Débridement			Salvage			Reconstruction				Hand (%)
		Débridement (%)	Exploration (%)	Total (%)	Revascularization (%)†	Bone Stabilization (%)	Total (%)	SSG (%)	Flap (%)	Nerve Reconstruction (%)	Total (%)	
2009	131	82 (63)	15 (11)	74	6 (5)	8 (6)	11	7 (5)		1 (1)	6	12 (9)
2010	178	116 (65)	21 (12)	77	12 (7)	3 (2)	9	9 (5)	3 (2)	2 (1)	8	12 (7)
2011	199	113 (57)	12 (6)	63	13 (7)	7 (4)	11	24 (12)	10 (5)	3 (2)	19	17 (9)
2012	137	97 (70)	5 (4)	74	10 (7)	4 (3)	9	14 (10)	4 (3)		13	3 (2)

SSG, split skin graft.
*Percentage of total plastic surgery cases that were débridement, salvage, reconstruction, or hand.
†Includes unspecified salvage and repair.

been attributable to survivor bias in the non–body-armored group (i.e., those with significant trunk/torso injuries did not survive to the field hospital). This has implications for the role of plastic surgeons in future deployed military teams, as they appear to have utility irrespective of the type of injury pattern.

The majority of work performed by plastic surgeons was surgical débridement, with salvage and reconstructive procedures being performed less frequently. This is to be expected, as the treatment pathway for coalition forces involves multiple, staged procedures at deployed and home base locations. Definitive reconstruction is delayed until the appropriate time away from the combat zone. The débridement, particularly of specialist areas such as the face and upper limb, is the critical first step in achieving optimum functional outcomes for casualties. If it is not done adequately, there is risk of developing wound infection and sepsis. This can prove a risk to life and to limb, as many of the infective organisms encountered in combat operations in Afghanistan were multidrug-resistant and difficult to treat pharmacologically. Decisions around extent of débridement carried out were made on a case-by-case basis by the multidisciplinary team to reduce the likelihood of débridement that is too aggressive and thus leads to the loss of reconstructive options or salvageable tissue and thus compromise a casualty's final functional result.

The additional challenge of improvised explosive device blast wounds is extent of the zone of injury. It is not uncommon for over 50 percent of the body surface area to be affected, with multiple limb amputations. Débridement of wounds of this size is a major endeavor for surgical teams and should be carried out quickly and thoroughly by subject matter experts. Meticulous débridement, with a clear understanding of the future reconstructive options, is the foundation for achieving the best outcomes in this patient group. This is a skill that is fundamental to all military surgeons, but the plastic surgeon contributes to this in specialist body areas.

Although the proportion of reconstructive procedures was small, this increased during the study. This was not statistically significant but coincided with a significant increase in the proportion of Afghan National Security Forces casualties. It is likely that the two are linked. As stated, coalition casualties are repatriated for future management, including definitive reconstruction. Local nationals did not have this option during this conflict. Reconstructive procedures were performed on this group if they would lead to quicker wound healing (and more rapid discharge) and/or better functional results. All such decisions were made within the context of the activity of the medical treatment facility. Negative-pressure wound therapy was introduced in 2011, and this also helped with wound care.

The limitation of this study is that there is no objective evidence of improved functional outcomes from having a plastic surgeon as part of the team. This is difficult to clearly demonstrate, for various reasons. The main issue is that there is not a valid control group (i.e., same team but without a plastic surgeon) for comparison. The U.S. surgical team based in Kandahar did not routinely use a plastic surgeon as part of their establishment. However, differences in their patient pathways and in the patient cohort precluded direct comparison with the current data set. Data from Camp Bastion that predate 2008 and the deployment of the plastic surgeon would also be noncomparable. The prehospital and acute pathways evolved rapidly so that the care being delivered in 2008 differed from that in 2009. However, there is evidence from civilian data for the efficacy of having a plastic surgeon involved in severe extremity trauma. Wordsworth et al. looked at a series of 139 open tibial fractures treated sequentially in an urban major trauma center in the United Kingdom. They found that by using an integrated team of orthopedic and plastic surgeons, the outcomes were significantly better than those reported in the literature that did not use the approach (deep infection, 1.3 percent versus 38 percent; nonunion, 3 percent versus 50 percent).[10] A study examining the long-term outcomes of all casualties from recent conflicts is currently underway. This may provide evidence for the benefit of having a plastic surgeon as part of the team. The present cohort study did not allow analysis of the number of delayed amputations that were carried out; however, a comprehensive database is available from 2016 and will enable further analysis.

This study shows that if plastic surgeons are deployed as part of a military surgical team, they contribute to a large proportion of the surgical activity. This contribution was irrespective of the injury pattern. The plastic surgeon brings skills and expertise in body areas that will be absent from a team composed solely of orthopedic and general surgeons. They should be seen as complementary to the team. This study shows that a team consisting of plastic, orthopedic, and general surgeons can manage almost all injuries sustained in modern conflict using their normally practiced and therefore maintained skill sets. Plastic surgery grew out of war; this study suggests that war remains its natural home.

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Appendix 2: Subject related international presentations

International presentation of: The role of plastic surgeons in frontline combat operations: a three-year evaluation, at the Winter Scientific Meeting, 27-29 November 2013, meeting hosted by the British Association of Plastic and Reconstructive and Aesthetic Surgeons (BAPRAS), The Convention Centre, Dublin, Ireland.

Appendix 3a: Microsoft Excel Spreadsheet of the Maitland Module

	A	B	C	D	E	F	G	H	I	J	K	L
1	cohort	serial no	date	age	hospital no	nationality	injury mec as d	Mec Interpret	operation code	Emergency (as	ward	type of procedure (
8234	12	12635	13/08/2012	N	N	N	N	N	4	N	wd	2
8235	12	12636	13/08/2012	N	N	N	N	N	3	N	wd	2
8236	12	12637	13/08/2012	N	N	N	N	N	1	N	wd	2
8237	12	12638	13/08/2012	N	N	N	N	N	4	N	wd	2
8238	12	12639	13/08/2012	N	N	N	N	N	3	Y	wd	2
8239	12	12640	13/08/2012	N	N	N	N	BLAST	1	Y	ed	1
8240	12	12641	14/08/2012	N	N	N	N	N	3	N	wd	2
8241	12	12642	14/08/2012	N	N	N	N	BLAST	4	N	ilo beds	1
8242	12	12643	14/08/2012	N	N	N	N	N	3	N	wd	2
8243	12	12644	14/08/2012	N	N	N	N	BLAST	1	Y	ed	1
8244	12	12645	14/08/2012	N	N	N	N	N	3	N	wd	2
8245	12	12646	14/08/2012	19	N	N	N	N	3	N	wd	2
8246	12	12647	14/08/2012	N	N	N	N	BLAST	1	Y	itu returned	1
8247	12	12648	14/08/2012	N	N	N	N	BLAST	2	Y	ed	1
8248	12	12649	15/08/2012	N	N	N	N	BLAST	3	Y	ed	1
8249	12	12650	15/08/2012	N	N	N	N	BLAST	1	Y	ed	1
8250	12	12651	15/08/2012	N	N	N	N	BLAST	4	Y	ed	1
8251	12	12652	15/08/2012	N	N	N	N	BLAST	2	Y	ed	1
8252	12	12653	15/08/2012	N	N	N	N	BLAST	1	Y	ed	1
8253	12	12654	15/08/2012	N	N	N	N	N	2	Y	wd	2
8254	12	12655	15/08/2012	N	N	N	N	N	4	Y	itu	2
8255	12	12656	15/08/2012	N	N	N	N	BLAST	1	Y	ed	1
8256	12	12657	15/08/2012	32	N	N	N	N	3	Y	wd	2
8257	12	12658	15/08/2012	19	N	N	NBI	NBI	1	Y	wd	1
8258	12	12659	15/08/2012	10	N	N	N	N	3	Y	wd	2
8259	12	12660	15/08/2012	N	N	N	N	BLAST	1	Y	ed	1
8260	12	12661	15/08/2012	28	N	N	N	N	3	Y	wd	2
8261	12	12662	16/08/2012	N	N	N	N	N	3	N	itu	2
8262	12	12663	16/08/2012	30	N	N	N	N	4	N	wd	2
8263	12	12664	16/08/2012	N	N	N	N	BLAST	1	Y	ed	1
8264	12	12665	16/08/2012	N	N	N	N	N	3	N	itu	2
8265	12	12666	16/08/2012	N	N	N	N	GSW	1	Y	ed	1
8266	12	12667	16/08/2012	N	N	N	N	BLAST	2	Y	not doc	1
8267	12	12668	16/08/2012	N	N	N	N	N	3	Y	wd	2
8268	12	12669	16/08/2012	N	N	N	N	BLAST	1	Y	not doc	1
8269	12	12670	16/08/2012	24	N	N	NBI	NBI	1	Y	not doc	1

Sheet1 Sheet2 Sheet3

Appendix 3b: Microsoft Excel Spreadsheet of the Maitland Module

M: who did it	N: time in th	O: time out	P: duration	Q: injury zone	R: Optype - free text	S: upper contr	T: GA/LA	U: signature ANSFesthe	V: DOT/DO	W: comments
Name removed to protect surgeons' identity	8:35 AM	10:23 AM	01:48:00	LUE	re-look left arm and abdomen wounds	N	GA	signature removed to protect the identity of anaesthetists	N	
	8:34 AM	10:34 AM	02:00:00	RLE, TW	closure AE* stump right; SSG to chest wall	N	GA		N	TNP *AE??
	10:46 AM	1:48 PM	03:02:00	RUE, TW	fillet index finger right hand to re-surface *spine,	N	GA		N	*resurface?
	11:00 AM	12:15 PM	01:15:00	TW; RLE	relook abdominal wound; inspect redress right th	N	GA		N	tnp
	3:25 PM	4:12 PM	00:47:00	face	closure of scalp wound	N	GA		N	
	3:39 PM	5:10 PM	01:31:00	RUE; face	exploration and debridement of wound to right w	N	GA		N	nil
	8:24 AM	9:55 AM	01:31:00	LLE; RUE hand	washout and debridement left stump BKA; adjust	N	GA		N	tnp
	9:27 AM	12:35 PM	03:08:00	AC	laparotomy and multiple small bowel anastomose	N	GA		N	kerlex to iliac wound
	10:35 AM	2:50 PM	04:15:00	BLE	bilateral lower extremities SSG and DPC	N	GA		N	tnp x3
	2:30 PM	6:10 PM	03:40:00	AC; LUE axilla;	laparotomy; vascular control axilla Left; fasciotom	Y	GA		N	NNP x2
	3:20 PM	5:49 PM	02:29:00	LUE hand	open reduction left fifth PIPJ	N	sedation with local		N	
	6:50 PM	8:15 PM	01:25:00	eye; LUE/hand	enucleation left eye; suture nailbed laceration an	N	GA		N	
	7:15 PM	11:30 PM	04:15:00	BLE; RUE hand	BKA right side; saphenous vein graft from right si	Y	GA		N	TNP x2
	8:12 PM	12:30 AM	04:18:00	CC; AC	exploratory thoracotomy and laparotomy, TNP a	N	GA		N	30x30x2 in abdomen TNP
	3:00 AM	7:40 AM	04:40:00	LLE	graft popliteal artery fasciotomy; exfix left leg	Y	GA		N	tnp
	2:57 AM	4:47 AM	01:50:00	AC; CC	exploratory laparotomy; bowel resections x3; che	N	GA		N	
	3:30 AM	5:36 AM	02:06:00	BLE; BUE	I+D BLE and BUE; exfix BLE	N	GA		N	tnp
	3:40 AM	5:40 AM	02:00:00	AC; CC; RLE	exploratory laparotomy and bowel resection and	N	GA		N	tnp; 30x30x1 in abdomen
	5:15 AM	7:20 AM	02:05:00	AC	laparotomy: removal of spleen (splenectomy) and	N	GA		N	
	6:00 AM	7:55 AM	01:55:00	AC	laparotomy with bowel resection and catheterisa	N	GA		N	tnp 2x30x30 in abdomen
	6:30 AM	8:08 AM	01:38:00	LUE/hand; LLI	I+D left hand; I+D/ex-fix left femur	N	GA		N	
	7:43 AM	9:45 AM	02:02:00	AC; CC	exlap: pack liver; TNP and chest drain and diaphra	N	GA		N	tnp 4x lap swabs in abdomen
	8:22 AM	11:55 AM	03:33:00	CC; LUE	insert chest drain; exlap; I+D left arm wound	N	GA		N	24 fr chest drain and 10mm JP d
	9:42 AM	1:06 PM	03:24:00	AC	laparotomy appendectomy	N	GA		N	
	12:10 PM	1:30 PM	01:20:00	AC; LE; AC; TW	exlap; D+I hip; repair right hemi-diaphragm; debri	N	GA		N	*rings?
	2:55 PM	7:15 PM	04:20:00	AC; LUE; RLE	laparotomy; right external iliac artery repair; fasci	Y	GA		N	tnp for abdomen; 1x30x30 in ab
	8:05 PM	9:45 PM	01:40:00	LLE; perineum	debridement medial left knee wound and left foo	N	GA		N	
	8:30 AM	10:45 AM	02:15:00	AC	laparotomy with bowel anastomosis x2 and closu	N	GA		N	
	8:52 AM	10:50 AM	01:58:00	BLE	D+I Bilateral lower extremities	N	GA		N	tnp
	10:22 AM	12:40 PM	02:18:00	BLE; LUE	bilateral BKA; left arm amputation; laparotomy; D	N	GA		N	
	11:40 AM	2:00 PM	02:20:00	AC; eye; face	laparotomy with bowel anastomosis; OD enucleat	N	GA		N	
	1:14 PM	3:01 PM	01:47:00	AC	laparotomy	N	GA		N	tnp
	2:19 PM	7:00 PM	04:41:00	AC; perineum,	exploratory laparotomy and placement of x2 uret	N	GA		N	2x abdo swabs left in pelvis, TNF
	2:54 PM	4:15 PM	01:21:00	BUE, BLE	exploration right forearm; I+D left thumb, I+D BLE	N	GA		N	
	3:45 PM	4:30 PM	00:45:00	AC	emergency laparotomy for bleeding control	Y	GA		N	tnp
	4:47 PM	5:40 PM	00:53:00	LE	toe amputation/I+D	N	GA		N	

Appendix 3c: Itemisation of data

In order to manage the dataset, additional columns were inserted in order to facilitate data mining. These are indicated below in bold font.

The columns were labelled consecutively with the letters of the alphabet and reading across the theatre log books from left to right the columns ran A-W (see Appendix: Excel Spreadsheet).

Table 1: Itemisation of data

A	Log book number: each surgical theatre log-book had a number ascribed to it e.g. 1-2-3
B	Serial number: a unique number given to each case that goes up sequentially
C	Date: The surgical case performed
D	Age: where documented recorded as years or months if paediatric e.g. 13M = 13 months old.
E	Hospital number
F	Nationality where documented and categorised into: ANSF; ISAF; CIV; and PAED
G	Mechanism of injury where documented
H	**Mechanism of injury from operative text**
I	Theatre table number: 1,2,3,4
J	Documented as an emergency procedure or not: Y/N = yes or no

K	Where the casualty came from for the operation: Emergency Department, Intensive care; ward or x-ray
L	**Procedure type:** Primary or Secondary Primary case: initial surgery carried out, and the initial surgical interventions thereof to stabilise the patient. Secondary case: take-back surgery carried out thereafter, and subsequent cases on the same casualty.
M	Names of surgeons operating (names used for analysis only and anonymity is preserved in this thesis)
N	The time documented into theatre or start of the operation
O	The time documented out of theatre or end of the operation
P	**Length of operation in minutes.**
Q	**Anatomical /body region operated on:** It was possible to itemise and categorise each procedure to body regions operated on outlined as follows: AC: abdominal cavity control/not CC: chest cavity (included chest drains)

	TW: Torso wall (includes back, scapula) and flank F: face including scalp, ears and nose, and jaw E: eyes (usually written as eyes) E: extremities e.g. BUE is bilateral upper extremities H: head – including neuro N: Neck (including clavicles) B: buttock region (hip sometimes as buttock) T: thigh (LT/RT) or LE (lower extremity) P: Perineum: (scrotum; penis; perineum itself; anus) (rectal, urethral/urethra…) F: foot LL: Lower limb UL: upper limb (upper limb includes hand and wrist) H: Hand UE: upper extremity (including hand) LLE: Left lower extremity LLL: Left lower limb

	LE: lower extremity (not always stipulated L/R) RLE: Right lower extremity BLE: Bilateral lower extremities B/L: bilateral or bilateral free-text B as prefix to UE/LE etc see below LUE: left upper extremity includes hand and wrist RUE: Right upper extremity includes hand and wrist BUE: Bilateral upper extremity A: Axilla: MF: middle finger RF: ring finger IF: index finger (L+R) Usually Free-text: Head Neck Eyes Pelvis mouth Hand

	Rectal sometimes recorded just as rectal Axilla: usually recorded as axilla Clavicle sometimes on its own but usually included in UE or neck depending on the operation performed Groin: groin
R	Operation details and surgical procedural details as written in the log-book and directly transcribed.
S	**Proximal vascular control:** proximal control required Y/N Yes/No
T	Anaesthetic and anaesthetic procedures: RSI: Rapid Sequence Induction MTP: Massive Transfusion Protocol LINES: LIJ (Left Internal Jugular), external jugular, A-line (Arterial line), SCL (Subclavian line) TCI Target Controlled Infusion GA: General Anaesthetic LA: Local Anaesthetic BLOCK: Sciatic; Femoral; Regional Block; Epidural; Spinal LMA Laryngeal Mask Airway

	ETT Endotracheal Tube IPPV Intermittent Positive Pressure Ventilation Extubation GA General Anaesthetic LA Local Anaesthetic Sedation Airway adjuncts
U	Signature/name of the anaesthetist (anonymity preserved)
V	DOW – Died of Wounds after reaching surgical facility; Yes or No –Y/N
W	Comments: as per documentation in the log-book including any additional information including dressing types; swab numbers etc.

Appendix 4: Ministry of Defence Research and Ethics Committee

MOD Research Ethics Committee email

Before the study was initiated, the database was approved by the MODREC (Ministry of Defence Research and Ethics Committee).

MOD Research Ethics Committee <modrec@mail.dstl.gov.uk> 4/28/17

to me

Classification: UK OFFICIAL

Dear Laura

As discussed, the fact that is registered as an MD with the University of St Andrews makes no difference to the determination that MODREC approval is not required on the basis of the information you have provided.

Kind regards

Gill

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