Safety Standards for Police Body Armour

by

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Abstract

Assaults on the Police continue to increase. Of particular concern is the threat of injury from edged weapons. Shootings remain rare. The Home Office has embarked on a program to provide all police officers with suitable body armour.

Body armour has been on general issue to police officers in America for over twenty years and has a superb record in saving lives from shootings. Little is known about its ability to prevent serious stab wounds from knives, as this is a much less common threat in the American policing environment. Therefore the specification for armour for police use in this country must be set to provide protection against the threats in the UK policing environment.

Current knife-resistance standards are based on animal experimentation and have not been examined by any other model. To understand the protective requirements of armour, it is necessary to understand the weapon threat, the assailant's method of delivery, and the vulnerability of the target.

The biophysics of human stabbing (the assailant's method of delivery), is the subject of ongoing investigation, and is outwith the scope of this thesis.

In this thesis, the history and development of body armour is reviewed. An overview of the materials and properties of modern armour is presented. To understand the threat, the epidemiology of assaults on police officers and civilians is described.

To determine the ideal protective qualities of body armour for issue to the police, two studies are presented.

The first is a retrospective cohort study of 500 civilian victims of penetrating injury. The frequency of wounding, and the severity of wounding by body region is plotted on anatomical charts. This will demonstrate the vulnerability, and hence the protection requirements of each body area to penetrating injury.

No previous study has measured the depth of the internal organs from the skin. A CT study is presented. It describes the accessibility of the internal organs to the passage of a blade by measuring the shortest distances from the skin.

By applying the results of these two studies to the location of the internal organs (which lie in fairly constant relation to surface anatomy landmarks), the ideal protective qualities of armour panels over corresponding areas of organ vulnerability are plotted. The case for adopting three levels of knife resistance protection is made.

The ballistic protective requirements of body armour are discussed.

Finally, proposals for zoned body armour are presented and ergonomic and production issues are described.

The model presented in this thesis has been accepted in principle by the Police Scientific Development Branch of the Home Office with a view to establishing a zoned body coverage requirement for police body armour.

PART 1: INTRODUCTION

Introduction

Throughout history, combat weapons have killed and caused injury by their ability to cut, pierce, or crush. From very early times body armour has been designed to protect the wearer from these threats. Body armour evolved with each development in weaponry and was ultimately defeated and abandoned after the introduction of firearms in the 19th Century.

Recent technological advances have led to the development of new materials that are light and flexible, capable of absorbing large impacts and preventing, or greatly impeding, the passage of edged weapons and projectiles. There has, therefore, been a recent resurgence of interest in body armour for both civilian and military use.

Protection afforded by body armour can be defined in two ways:

1. protection from serious physical injury and death

2. protection from incapacitation after an assault - that is, the victim's ability to continue to engage an opponent after an assault and not to be rendered defenceless and susceptible to a potentially fatal second assault.

Modern armour can be made to withstand knives or bullets, or knives and bullets. The physical properties and hence the 'wearability' of the armour will vary according to its protective qualities. Armour made to defeat knives will be more flexible than a garment designed to protect against bullets. Combination armour for protection against both knives and bullets incorporates two different technologies and is necessarily heavier and less flexible than single purpose armour. It is consequently less wearable.

Modern body armour manufacturers face the same challenges as their predecessors. To be practical for routine use, armour must offer the best possible protection against specific identified threats, without unduly hindering the wearers in the performance of their duties. Wearers must be able to carry out their duties in their normal working environment and carry and deploy their equipment comfortably and effectively. The ergonomics of armour are therefore important for regular wearers.

Body armour for regular wearers must be relatively light and flexible. Its weight distribution must be considered for both male and female users. Its heat-retaining properties need to be acceptable for use over a working shift in most weathers.

Appearance

In ancient times, military armour also served to denote rank and wealth. Armour was often augmented to make the wearer appear larger and frightening to the enemy. For contemporary military and police wearers, the armour must have an appropriate appearance and be incorporated into uniform patterns. For civilian wearers (protected persons) the armour needs to be concealed (covert).

Modern policing dictates that officers must not appear threatening to the public. They need to be seen as approachable while maintaining a smart and authoritative image. Police authorities are concerned that police wearing body armour should not look like ‘streetfighters’, and in any event should not adopt a paramilitary appearance. Their armour must therefore be unobtrusive whether it be worn as a covert garment, or incorporated subtly into uniform worn overtly.

Risk Assessments

The body armour user requires armour that offers the best available protection against the most likely threats for that user’s working environment. To determine the desirable protective properties of armour for the police, a risk assessment is required. This needs to consider the wearers’ policing role and the likelihood of knife and ballistic assaults in that particular environment and role. This can usually be determined by examining statistics on violent activity in each area and by operational duty. A review of confiscated weapons is also very useful in determining the threat on the street. This is presented later.

Most police forces record violent incidents, injuries and use of force incidents. At present, the method of collating this data is not standardised across the country, and therefore the accuracy and relevance of data vary widely between different police forces.

Accurate and relevant risk assessments will enable police forces to predict the threat to their officers by area and operational duties. For most forces in this country it will become evident that the ballistic threat is minimal and the most appropriate body armour would be one that confers maximal protection against edged weapons.

Knowledge of the common injuries sustained in assaults on police officers will also be important. This information will determine the predominance and nature of weapons used and which parts of the body are most at risk.

Injury to some organs will be more devastating than injury to others. For example, a penetrating wound to the heart is likely to be more life-threatening than a wound of similar dimensions to a limb. Therefore, the vulnerability of each organ and body area needs to be determined. The physical properties of different parts of the body need to be considered.

The accessibility of organs (distance from the skin) is another important factor. For knife protection we need to determine how far a knife can be pushed into any part of the human body before it penetrates and damages the internal organs. This will provide a benchmark for the knife resistant requirements of body armour.

When a bullet is arrested by body armour, the armour is deformed and a crater develops. This results in a reciprocal depression on the inner surface of the armour. The size of this depression is known as backface deformity and is measured in millimetres. For ballistic strikes we need to determine the likely effects and injury potential of this depression into the body by area.

By combining these factors it will be possible to plot a risk analysis for each area of the body. This information will allow armour manufacturers to produce armour that provides appropriate protection against specific threats to those areas of the body most at risk. It may be that the most suitable armour employs different technologies over different areas of the body reflecting the different threats to each body area.

This thesis will describe the evolution of armour and identify those aspects used in determining a risk assessment for routine police work.

The risk of injury from stabbing will be evaluated by :

- describing the epidemiology of assault
- presenting a retrospective cohort study on wounding in 500 victims of penetrating trauma, describing the frequency and severity of injury by body area
- presenting a retrospective CT study describing the skin to organ distances in adults.

This information will be used to draw a regional anatomical risk map. From here, it will be possible to determine the degree and type of body armour required for each of the body areas. Ergonomic considerations will be discussed and a model design for male and female armour will be presented.

PART 2: HISTORY OF ARMOUR - AN OVERVIEW

Introduction

The history and evolution of armour is presented. For this, and the following section, historical information was taken from two reference texts, supported by information on display at the Smithsonian Institute in Washington DC [1,2]. Photographs were taken by myself at the Smithsonian Institute.

Armour

From very early times, armour for the fighting man and his steed was developed to keep pace with evolving weapons and battlefield tactics. Between the 13th and 17th Centuries, plate armour evolved to counter improvement in blade-making techniques and the introduction of missile weapons.

In the 16th and 17th Centuries, improved weapons forced armourers to increase the thickness of their product. This resulted in an increased weight and bulk of the armour, so that eventually it became too cumbersome for the soldier to wear and function effectively on the battlefield. Plate armour was therefore largely abandoned. Some European cavalry units retained remnants of plate armour in the form of a cuirass or hat lining until these too were rendered obsolete by the introduction of more powerful firearms.

Historical armour can be divided into four main construction designs:

- Leather
- Fabric
- Mail
- Rigid plate.

Leather armour

Hide armour is probably the oldest of all body armours. Coats made of five to seven layers of rhinoceros skin were worn in China in the 11th Century. The Mongols used a similar design of ox hide in the 13th Century. North American Indians adopted similar patterns using horse leather.

Stout buff leather coats were worn underneath European plate armour in the 16th Century. The leather sleeves and skirts, retained after the plates were abandoned were strong enough to deflect a sword cut and in this way, buff leather continued to be used for the cuffs of cavalry gauntlets until the 19th Century.

Fabric armour

The oldest fabric armour, consisting of fourteen layers of linen, was found in a Mycenaean grave of the 16th Century BC. The Greek infantry of the 5th – 4th Centuries BC wore a linen cuirass in preference to bronze. In the Middle Ages quilted coats (aketons) were worn either alone or under mail or plate armour to prevent chafing.

Velvet covered quilted coats, studded with small gilt nails were worn in India until the 19th Century. This armour incorporated steel plates on its surface, covered the trunk, neck, shoulders and upper arms, and extended as a skirt to cover the groins and thighs.

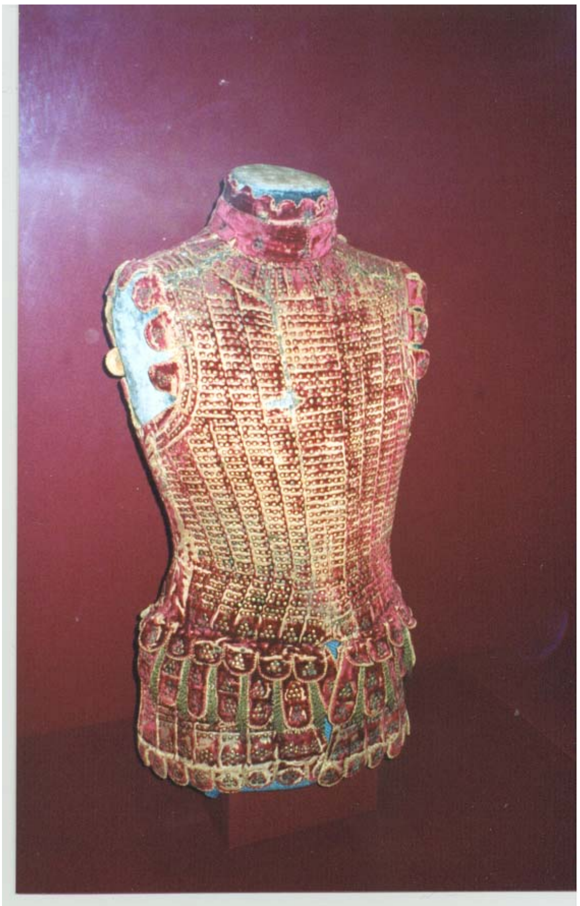


Figure 1: 18th Century Indian quilted coat

Rope armours of coir (coconut husk fibre) were worn until the 19th Century in the Gilbert and Ellice Islands.

Figure 2: Coconut husk armour from the Gilbert Islands

The development of aramid fibres and Kevlar ® in the 20th Century brought about a renewed interest in fabric armours that provide protection in a relatively light garment that does not unduly hinder the performance and mobility of the wearer.

Kevlar ® - based armour was widely issued to American soldiers in the Vietnam conflict to protect against shrapnel. It was, and still is not ‘bullet proof’. This type of soft armour continues to be used by most modern armies as ‘flak jackets’.

Figure 3: American soldiers were issued soft armour in the Vietnam War

Mail armour

Mail armour consisted of interlocking iron or steel rings. Its production was extremely labour intensive. Mail is flexible and impervious to slashing strokes when worn over quilting. However, a thrusting weapon can force the rings apart. Once this failure occurs, protection is lost.

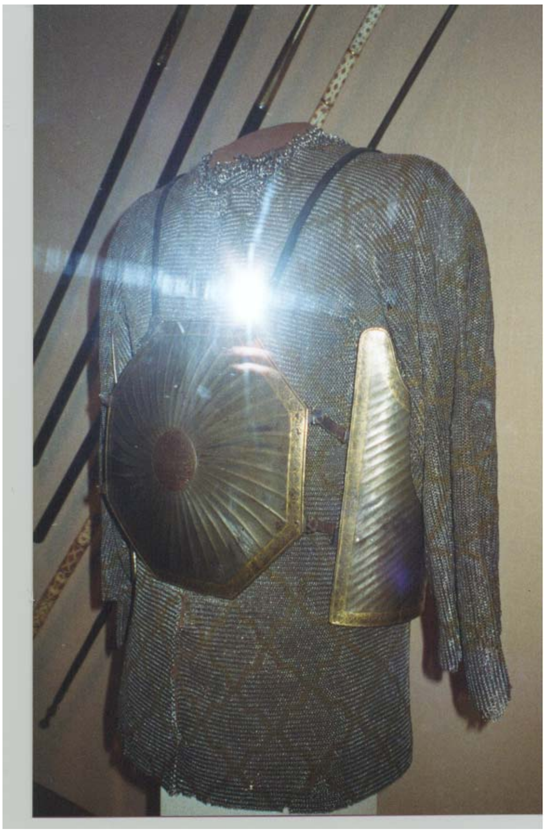


Figure 4: A chain mail coat with outer plate armour

The earliest surviving example of mail armour, dating from the 5th Century BC, was found near Kiev. Mail armour in the form of a simple shirt was worn throughout the Roman Empire and beyond most of its frontiers. It survived as the main armour of Western Europe until the 14th Century. Leg harnesses and hoods were introduced in the 11th Century, and later long sleeves and gloves appeared.

A combination of mail shirt and aketon was worn in India and Persia until the 19th Century, and survive in the Sudan and Nigeria today.

Following the development of plate armour in Europe, mail gussets were laced to cover the gaps between plates. A curtain of mail was often attached to the lower edge of the helmet to protect the neck.

Figure 5: Combination plate and mail armour

Rigid plate armour

Rigid plate armour employed metal, whalebone, ivory, horn, bark, wood, plastic or cuir-bouilly (leather hardened by boiling in wax). It can be divided in different categories according to the methods of connecting the pieces:

- Scale armour - small overlapping plates attached outside a leather or fabric garment. Examples have been found from 17th Century Egypt and throughout the Middle East and Europe. It was worn in India and China until the 19th Century and was readopted at that time by European heavy cavalry for use as shoulder protection.

- Brigandine - small overlapping plates attached inside a leather or fabric garment. Armour of this design was worn in 8th Century China and later in Korea until the 19th Century. Brigandine armour has been excavated from 14th Century European sites and similar examples are seen in paintings from about 1240. These remained the most common forms of armour until about 1400. After 1360 a one-piece breastplate was usually put under the outer cover. Short brigandine coats were widely used by European troops until 1600.

- Lamellar - small overlapping plates in strips held together by laces. The strips had a vertical long axis, each overlapping its neighbour. This armour was more flexible than scale armour and was easier and cheaper to manufacture. Lamellar armour originated in Persia and was later adopted by armies to the East and the West. It was elaborately embellished by the Japanese during the Heian period (794 – 1185) and remained in use there until 1867.

Figure 6: Two examples of Japanese lamellar armour

- Plate and mail – small plates held together by mail or let into mail garments. This design first appeared in Persia and Turkey in the 15th Century in the form of hoops around the body with smaller overlapping plates in the arms and skirts. Full armours of this type, including helmets and trousers, were used in India between the 17th and 19th Centuries. Horse and elephant armours were made in the same way.

- Large plates – held together by loosely closed rivets and by internal leathers. This design allowed the wearer maximum freedom of movement.

Figure 7: An example of Japanese large plate armour

Design, decoration and symbolism

Body armour evolved to counter the threat from new battlefield weapons. Armour was embellished to varying degrees to demonstrate rank, identification, contemporary style, affiliation and personal wealth.

In many cultures, the right to bear arms was a privilege, and arms and armour therefore became symbols of socio-economic status.

In Homer's Iliad we read of *"the dreadful crest nodding from the helmet's peak"*, overemphasising the height of the warrior to intimidate the enemy. Japanese Samurai warlords wore grimacing war masks *(menpo)* to terrorise their opponents.

The design of historical armour also reflects the prevailing artistic style of the time and region. In Europe, for example, there is a striking difference in style between 15th Century armour of the late Gothic period and 16th Century armour of the Renaissance. Gothic armour had accentuated vertical lines, and the general outline is dominated by a spiky elegance not unlike Gothic architecture. Renaissance armour was accentuated horizontally and had a more rounded appearance, in line with contemporary design, art and architecture.

Modern armour

Two types of modern body armour exist:

1. Soft fabric armour made of aramid fibres or Kevlar ®: usually worn covertly, concealed as a vest, it affords protection from most handgun bullets, shrapnel and offers some degree of knife resistance.

2. Hard plate 'bullet proof' armour: worn overtly for high risk operations, often over soft fabric armour. This type of armour is used by Special Weapons And Tactics (SWAT) teams or in circumstances where there is the expectation of rifle fire or stabbings. This armour is too hot, heavy and conspicuous for routine wear. It incorporates panels of sheet steel or titanium, sometimes coated with ceramic.

Soft knife-resistant armour needs a system to resist blade penetration. This is often chain mail, plates or cable weave attached to aramid fibres so that the energy of the knife thrust is dissipated after the arrest of the blade. Should the blade penetrate the knife system, the aramid fibres impede its further progress.

PART 3: THE EVOLUTION OF ARMOUR

Introduction

The disappearance of the war chariot necessitated lighter armour for the soldier. Greek armourers of the 7th – 5th Centuries BC produced a combination armour for the foot soldier consisting of a bronze cuirass, shin guards and a deep helmet.

Later bronze cuirasses modelled on the muscles of the torso were worn by Roman commanders. The Roman legionary wore a cylindrical cuirass of seven horizontal hoops of steel, with openings at the front and back through which they were laced together. Several half hoops extended to cover the shoulder, and a plate extended to cover the neck. The individual plates were linked internally by articulating leathers to allow maximum movement.

Armour of large plates was unknown in western Europe during the Dark Ages, but in the late 12th Century references were made to the cuirie, a leather armour reinforced with plates.

During the 13th and 14th Centuries, the entire body and limbs were gradually enclosed in plate, although the body armour itself until 1400 was usually of brigandine, sometimes having a steel breastplate fixed over it.

The complete steel body armour consisting of breast, back and a hooped skirt opening down the side, appeared in about 1400. Armour design continued to evolve during the 15th and 16th Centuries, with added reinforcement and adaptation for different types of combat. By the 16th Century, armour would consist of a number of pieces that could be added on, or taken off for use in the field or in tournament, mounted, or on foot.

As the importance of mobility and freedom of movement on the battlefield became understood, armour became progressively less bulky and by 1650, all but the cuirass and helmet had been discarded.

Plate armour, consisting of forearm defences and four large plates around the thorax, was worn in Persia and India until the 19th Century, usually over mail.

Historical armour was defeated and subsequently largely abandoned after the introduction of firearms in the 19th Century.

The nature of dressing for war changed dramatically in the Boer War. It was during this conflict that the importance of camouflage and mobility was realised. Unfortunately for the British, uniform and heraldry requirements were considered to be of far greater importance than battlefield functionality and soldier welfare. This had been obvious to other cultures many years before; the fighters for American independence could identify their red-coated enemy from great distances.

In more recent times, body armour has been re-explored for both civilian and military users. Flak jackets used by bomber crews in the second world war were heavy and cumbersome, but offered some protection from shrapnel. This evolved into the lighter flak jackets for infantry widely used for the first time in the Vietnam war. Subsequent military personal protection systems continue to grapple with safety versus comfort and operational requirements. Military specification body armour is usually worn overtly and can therefore be adapted to carry and combine with other items of equipment.

Body armour for civilian use (the police, personal bodyguards and VIPs) needs to be discreet and have a minimum impact on physical activity.

Police have a clearly defined role in modern society. This role has an image which is of the utmost importance to the interaction of the police and the public. Police officers must be seen as approachable but authoritative, smartly dressed with an easily identifiable uniform. The Association of Chief Police Officers do not wish Police officers to be seen as paramilitary ‘streetfighters’ or ‘Robocops’ [3].

The American Experience

American Police Officers continue to face a far greater threat of injury from firearms than their counterparts in Britain. This risk was recognised in the early 1970’s and coincided with the development of aramid fibres and Kevlar® by Dupont. Aramid fibres were initially developed by the tyre industry and were shown to be capable of dissipating large energies. Their potential value in stopping projectiles was soon realised. Soft covert armour has been on general issue to American police ever since.

This soft armour is almost exclusively made of Kevlar®. The protective qualities of this armour can be improved by adding additional layers of Kevlar®. These vests were designed to dissipate the energy of bullets. They were not specifically designed to stop knives, or other edged weapons, which have never been perceived as a major threat in the American policing environment. This is largely due to the fact that American police carry firearms, a fact which usually dissuades assailants armed with edged weapons.

The American experience has shown these vests to be extremely effective against bullets when the armour is worn correctly. Between 1980 and 1989, 801 American police officers lost their lives on duty. The Dupont Officer Safety Team consider that one third of these might have been prevented by the correct use of body armour [4].

In the same period, 166 officers were killed while wearing body armour. 95% of these were shot outside the protective area of the armour (54% head, 16% neck/upper torso, 8% lower abdomen, 7% shoulder/arm hole, 10% in the side) [1].

Eight officers died after their armour was penetrated by ballistic threats well in excess of the design capability of the armour. The death toll from knives has been extremely low and has not been reported nationally [1].

The American armour has also protected officers from other violence: knives, beatings, blunt assaults, falls and road traffic accidents. This evidence is largely anecdotal, and appears at times in police journals and news circulars.

PART 4: THE CASE FOR THE ISSUE OF BODY ARMOUR TO UK POLICE: THE THREAT OF VIOLENCE

Background

Armour is provided to protect the wearer from injury during assault. It is important therefore, to understand the prevalence and nature of assaults on police officers so that the armour can be designed to protect them from the actual risks. The risks facing officers will be shown to vary from region to region. Therefore, their protection requirements are also likely to vary.

Introduction

Data on assaults on police officers is collated annually by the Home Office. 'Serious' and 'minor' injury are not defined clearly on a national level. These definitions reflect classifications determined by local police forces reporting to the Home Office. Assault data from recent years is presented here [5].

Assaults on police

Table 1: Annual assaults on police officers

	1991	1992	1993	1994/5	1995/6	1996/7
Fatal	5	0	2	0	1	0
Serious	1,275	963	886	684	833	901
Minor	17,870	17,145	17,062	14,904	14,006	14,587
Total	**19,150**	**18,108**	**17,950**	**15,588**	**14,840**	**15,488**

The number of officers injured or killed by firearms remains very low. The use of edged weapons seems to be increasing and is a particular problem in some regions of the country [6].

There is no nationally-agreed framework for defining a 'serious' or 'minor' injury [5]. In some forces these definitions are purely subjective, while in others these are defined in terms of days off work, days in hospital or permanent disability or scarring. Notwithstanding these deficiencies, the reported overall number of assaults on police officers is likely to be reasonably accurate.

The Police Federation has long campaigned for greater protection for its members. It was assumed that the benefits of the American experience could be repeated in the UK by issuing officers with soft Kevlar® armour. It was widely known and accepted that many American officers had been saved by body armour. What was not realised was that American armour was good at stopping bullets but had no track record in stopping knives.

The threats to police officers in this country are very different to those in the US. The risk of an edged weapon attack is still far greater than that of a shooting.

On a national level, for the period March 1995 to March 1996, the Criminal Injuries Compensation Authority received 3140 applications from police officers wounded in the course of their duties. Of these, 149 (4.7%) were injured by a weapon. 42 (28%) of these weapons were knives, 11 (7%) firearms, 86 (58%) other weapons, and 10 (7%) 'glassing' in licensed premises [7].

For body armour to be effective in the UK, it has to offer protection against the threats prevalent in the UK policing environment.

On 17th May 1995 Home Secretary Michael Howard spoke to the Police Federation annual conference in Bournemouth:

'I know what risks and dangers police officers face every time they go out on patrol, and I want police officers to know that they have a Home Secretary who will back them.'

'I must make sure that the police service has the right tools for the job, whether that is suitable protective equipment or modern technology.'

'I know all chief constables are giving this subject urgent consideration. I am encouraging them to do so. Any chief constable who wishes to make body armour available to all officers will certainly have my support.'

The Police Scientific Development Branch (PSDB) of the Home Office was tasked to recommend suitable and appropriate armour for UK police. This was to be in terms of testing standards for both knife and bullet resistance. The development of these standards is discussed in a later section.

Her Majesty's Inspectorate of Constabulary was commissioned to examine the circumstances of assaults on police officers and suggest ways of reducing the threat. Six police forces were examined in detail. The need for a national officer safety strategy was recognised. Their report 'Officer Safety: minimising the risk of violence' was published in 1998 [5].

The authors recommended that police adopt a strategy based on informed risk assessments to determine the manner of deployment, the equipment required, the necessary training and standards of supervision. Consultation with experts on equipment development was considered crucial in developing officer safety.

It was recognised that equipment alone can never be the complete solution and all forces should have a clear and unequivocal policy on protective equipment, setting out what officers should carry according to the operational circumstances that they are likely to face. In particular, protective vests, batons and incapacitant sprays should meet the operational needs of individual officers.

The report states: *'An objectively informed risk assessment should be the only basis for issuing personal protection equipment, especially protective vests, and officers should be instructed about the equipment's protective limitations'.*

The introduction of CS incapacitant spray was seen as positive, as it increased confidence in conflict situations. Many police officers felt that it had made the baton redundant.

The report recommended that training should be consistent on a national level and led by National Police Training (an organisation based in Harrogate), with the emphasis on tactical communication skills as the first and most important tactic in conflict situations. The introduction of a conflict resolution model, use of force reporting and improved training in safe arrest, handcuffing and restraint of violent suspects subsequently evolved. Until only recently, each force had its own defensive skills training. There was great variability in the teaching of these skills: some were better than others.

Further to this recommendation, it was considered that forces needed to monitor the quality of their officer safety trainers to ensure compliance with national standards of training delivery. This has recently been instituted.

In recent years, police have been issued with CS incapacitant sprays, side-handled batons and improved handcuffs with appropriate training. The introduction of CS spray in 1994 has been credited with a reduction in the number of assaults from 17,950 to 15,588 [2].

The Epidemiology of Assault

The threat to police

It is difficult to accurately ascertain the threat and nature of assaults on police officers on a national scale as each force collates its own assault data. The methods and accuracy of reporting varies from force to force.

Relevant data from a report published by the Police Research Group of the Home Office examining the circumstances of assaults on police officers are presented [8]. This report describes the risk to police officers as a function of their type of duty. It does not contain details on injury severity as this document is based on collated data from all UK police forces whose reporting systems vary both in methodology and definitions of injury severity.

There are approximately 130,000 serving police officers in the UK. Most are operational, although the exact proportion of operational staff is not available. Policing carries a high risk of assault: in 1992, 14% of all police officers were assaulted, 0.76% sustained ‘serious injuries’ [8].

In general terms, approximately $^1/_3$ of assaults occurred before the officers had the opportunity to speak with their assailants, $^1/_5$ occurred when officers tried to calm individuals, $^1/_4$ of injuries were sustained when officers were attempting to restrain suspects at the point of arrest, and $^1/_4$ of injuries were sustained after an assailant had been detained [8].

More than one half of ‘serious injuries’ were sustained following traffic stops or dealing with disputes. Unexpected assaults produced the highest proportion of ‘serious injuries’ [8].

Weapons (of all types) were only used in 8% of assaults on police officers. Of these, more than $^2/_3$ were edged weapons. Most of these were used in attempts to escape arrest when caught at the scene of a crime and often involved the first available implement at hand. The surprise element seems to be a factor in increasing the officer's risk of assault [8].

In 1993 there were 17,950 reported assaults on Police officers, in 1995 there were 14,840. The drop in the number of assaults to from 1993 to 1995 has been credited to the introduction of CS spray. The spray allows incapacitation of potential assailants at a distance and reduced the number of baton draws by officers. There was also a reduction in the number of assailant injuries.

For assaults reported in 1994, the average age of assaulted officers was 28, and their average length of service was five years. It appears that more experienced officers have a smaller risk of being assaulted. It might be that their communication skills are better, or that they are seen as more authoritative than younger officers [8].

78% of police victims were on uniform patrol duties, 10% were involved in plain clothes work, and 12% on operational duties [8].

Anatomical sites of injury for police victims of assault

The anatomical sites of 'serious injury' are presented for 1994 [8].

Table 2: Anatomical sites of 'serious injuries'

Anatomical site	All assaults	Assaults resulting in more than 8 days sick leave
Face, head, neck	94 (42%)	9 (33%)
Trunk	14 (6%)	2 (8%)
Hands	31 (14%)	5 (21%)
Arms	27 (12%)	0
Legs, knee, foot	25 (11%)	3 (13%)
Multiple areas	35 (15%)	6 (25%)
Total	**226 (100%)**	**24 (100%)**

Location of assault

The location of assault[8] is presented in the following figures.

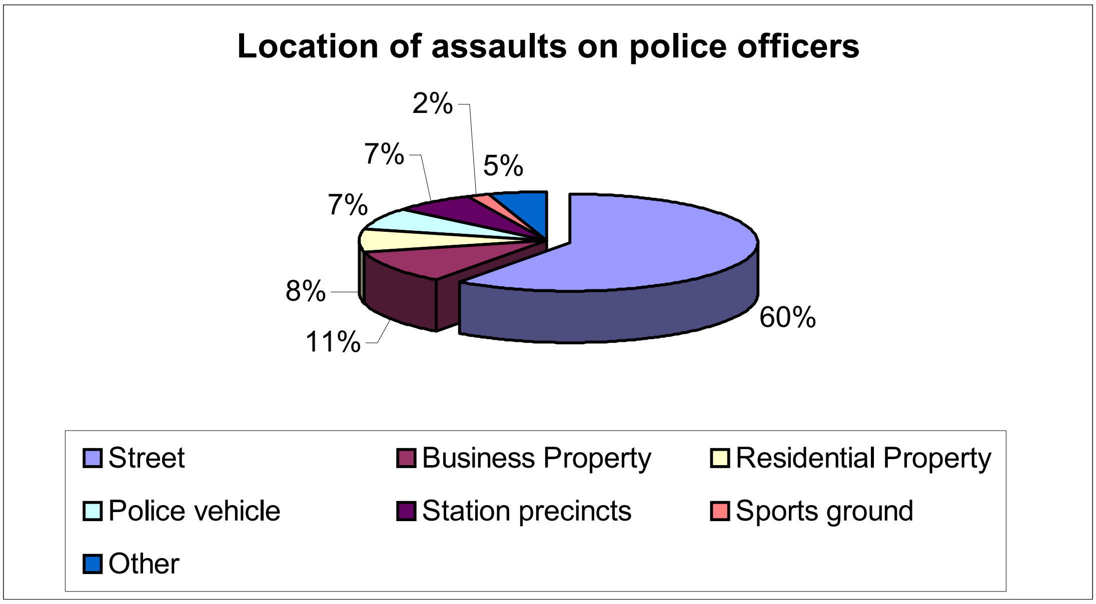


Figure 8: Location of assaults on police officers

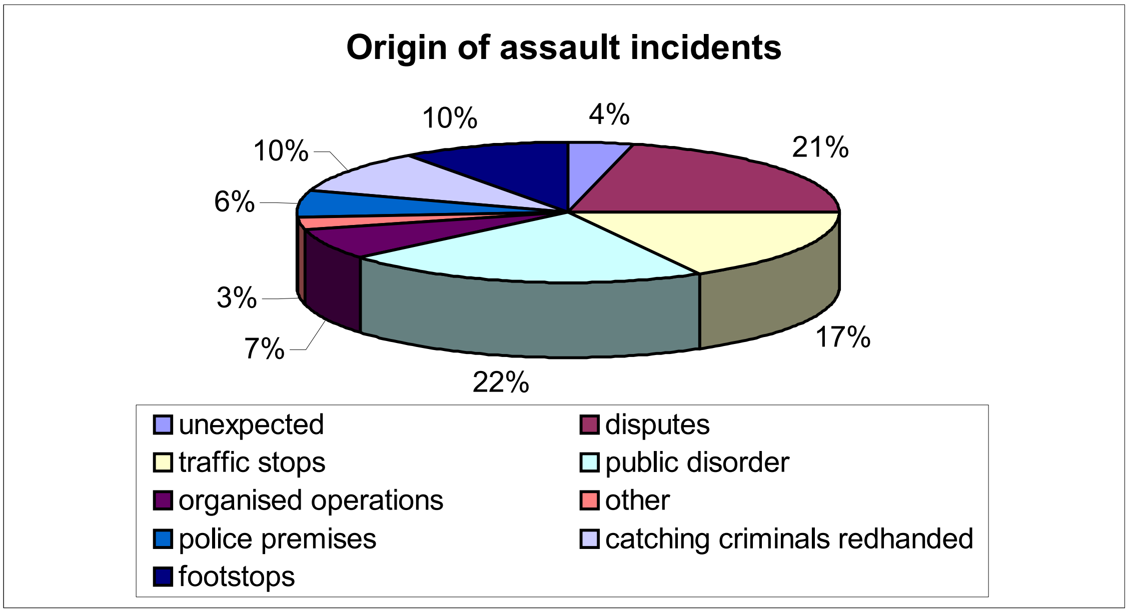


Figure 9: The type of police activity at the time of assault

It is clear from this Home Office report [8], that most assaults occur unexpectedly on junior police officers on routine uniform patrol duty in the street. This, therefore, is the population of police officers that most require protection from assaults. Body armour for them must provide appropriate protection against the most prevalent and likely types of assault threat in their working environment.

To learn more about the nature and prevalence of the threats to police officers, other published series are presented.

In the West Midlands, assaults on police officers are recorded. Officers are required to complete a form after every violent incident. However, 40.8% of officers surveyed, reported that they did not record minor assaults as the paperwork was considered to be too time consuming. It is reasonable to assume however, that most serious assaults are recorded [9].

Northamptonshire Police have had a system for reporting use of force incidents in place since 1995. It is used as an audit tool to measure the effects of new equipment, training and policing practise. Injuries to officers occurred in about 20% of use of force incidents [10].

In the first six months of 1997, Northamptonshire police made 9467 arrests. In only 580 (6%), was force required to execute the arrest and transfer the prisoner to custody.

In the 580 arrests requiring use of force by police officers, 101 suspects were injured [10].

Batons were used by police officers in 102 incidents. In 30 of these incidents, the offenders were armed with a weapon (15 of these were edged weapons, 14 were clubs and one was a motor vehicle) [10]. It follows, therefore, that in 30 of the 580 arrests requiring the use of force, the offender was armed. This represents 5%, of which approximately half were carrying edged weapons. The overall threat to a police officer in Northampton of arresting a suspect armed with a knife is 15/9467 (0.16%).

In the same period, there were 121 injuries to police officers in the 580 use of force incidents [10]. This represents a risk of 20.9% when engaged in a use of force arrest, and resulted in an average of 45 days of sick leave for each injured officer. None of the injuries were 'serious' and there was only one minor stabbing. Most injuries were bruises and abrasions to elbows and knees when the arrest occurred, after a struggle and wrestling suspects to the ground. This information prompted Northamptonshire police to examine their engagement and disengagement arrest tactics and control skills.

These reports provide some useful information on the threat faced by officers in the course of their duties. There are regional variations in assault patterns both between different forces, and also between different areas of the same force. This was recognised by the Home Office, Her Majesty's Inspector of Constabularies and the Police Federation. Their recommendation was for each force to determine its own risk assessment for assaults on police officers prior to deciding which protective equipment to purchase [2].

The epidemiology of assault on police officers has been presented. Information on patterns of wounding to officers in these assaults is limited. To further understand the threat to officers, it will be useful to present published data the epidemiology of assaults on civilians. This will provide more information on the injuries, weapons and patterns of assault faced by police officers.

Civilian assaults

National collation of data on assaults on police is incomplete and inconsistent. To further understand the risks faced by police officers on the streets, it is useful to look at data from series describing patterns of civilian violence. Relevant articles published in peer-reviewed journals were identified on Medline by appropriate key words. These provide an overview of the nature of assaults on civilians. From these, we can learn more about the prevalent injuries, mode of assault, the assailants and the use of weapons.

Only about half of civilian assaults are ever reported to police. Therefore data from hospitals treating the victims of assault will be more representative than police reporting of civilian assaults [11].

Articles describing the epidemiology and nature of assaults in civilian practise show that the physical pattern of assaults (weapons used, body areas attacked and methods of wounding) is similar for both police and civilian assault victims. However, police defensive training and the differences in the circumstances of confrontation may alter the nature of the violent encounter and account for small differences.

Civilian assault victims share some common characteristics: alcohol consumption is common, previous injury in assault is common, victims are largely young male adults and tend to be single [12].

A review of 572 assault victims from Strathclyde revealed that victims of violence made up 5% of all attenders to an inner city Accident and Emergency department. 77% were male with an average age of 28. Most assaults occurred at the weekend and tended to be out of hours. Approximately 20% of victims had penetrating injuries, the rest had sustained blunt injuries [13].

Assault patterns vary in different parts of the country. There are differences in the percentage of armed assaults and the types of weapon used. Seasonal variation in assault patterns is also recognised, that is, the frequency of assaults is related to the time of the year and the weather. The risk of assaults on police officers is likely to mirror these variations.

The pattern and mode of assaults has changed little in thirty years. A series from the Glasgow Royal Infirmary in 1967 identified that 71% of 147 stabbing victims attended hospital at the weekend; alcohol was involved in the majority of cases. 73% of victims were under the age of 30 and only 3% were female. 61% of injuries were to the chest, 43% to the abdomen, and 25% to other parts of the body. 23% of the victims received multiple wounds. 93% of penetrating chest wounds injured the lung and in 5% the heart was injured [14].

Penetrating wounds to the abdomen involved virtually all the internal organs with liver, mesentery and small bowel being the most frequently injured. The head and neck were involved in 17% of stabbings, while the lower limbs were involved in only 3% of stabbings. Injuries peaked in the early summer months [14].

A review from another centre in Glasgow during the same period showed that 66% of 142 stabbings involved the trunk, and were “often multiple” [15].

A series from the Glasgow Royal infirmary nearly 20 years later demonstrated little change: 96% of victims were male, the group being most at risk was men in their twenties. Stabbings peaked at weekends. The frequency of assaults also peaked at the weekend. The chest was involved in 45% of stabbings, the abdomen in 36%, the limbs in 33%, the head and the neck in 15% and the buttock in 5% [14,15].

Stabbing fatalities were mainly due to injuries to the left side of the body, principally to the chest. In single stab wounds, the heart was involved in 58% of fatalities. In these cases the lung was also frequently injured. In multiple stab wounds the chest was involved in 75% of fatalities [14,15].

In 1994, the picture in Glasgow had changed little. 77% of assault victims were male, most were assaulted at the weekend. Assaults peaked in the early summer months. Knives were used in 21% of assaults [13].

A series from Lewisham in London in 1989 confirms that most of 425 victims of assault were male (77%), 60% were under the age of 26, with 82% presenting out of hours [16]. The mode of assault in this series is presented here.

Table 3: Mode of assault in Lewisham

Punched, kicked, manhandled, or no weapon	77%
Knifed	15%
Miscellaneous blunt weapons	17%
Bottled/glassed	9%
Unknown	5%
Human bite	2%

(Some were injured in more than one way. Therefore the total is more than 100%).

There were no shooting victims. 63% of stabbings occurred in the street or in a pub.

Further information from three other London Accident and Emergency Departments shows similar patterns for 201 assault patients: 77% of assault victims were male, 53% of assaults occurred in the street or in pubs. 85% of the alleged assailants were male. 80% of these male assailants were estimated to be aged between 15 and 34 years [17].

More recent studies from around the country show that the only change over the last three decades has been the scale of the problem. The injury patterns have not changed significantly. Some examples are summarised below.

Most chest stabbings in London victims are inflicted by right-handed confrontational assailants to the left side of the body [17].

These series do not provide adequate anatomical resolution in describing the sites and frequency of penetrating injury of stab wounds. This information was provided by a retrospective study of 500 victims of penetrating injury and is presented later.

The nature of assaults in this country differs greatly from that in the United States. This is largely due to the availability of firearms. In one published American series, 42% of assaults were stabbings, and 12% involved the use of a firearm. 82% occurred in or near bars and most occurred out of hours. Alcohol was involved in 79% of assaults [18].

It is apparent from data collected by Northamptonshire Constabulary that assailants of police officers are a similar population to the victims of civilian assaults. Most assailants were young adult males, alcohol and drug use was common, many had been involved in previous violent incidents and many had prior criminal records [6,10]. It is evident that the majority of people involved in violence share some common characteristics.

There are clearly limitations in using civilian assault data to predict the threat to police officers. However, there is no similar information available for assaults on the police. In the next section, similar comparisons will be made between the two populations to describe wounding patterns in assaults. For this aspect of assault, there is more available information describing injury patterns in police victims.

Injury patterns in civilian assault

We have seen that most assault victims in this country sustain blunt injury. Edged weapons are responsible for between 10 and 20% of injuries in assaults [19]. Gunshot wounds are still very rare.

A series in Bristol revealed the following injury pattern for blunt injuries [19].

Table 4: Distribution of injuries in blunt assault in assault victims in Bristol

Site/type of injury	No. (n=854)	%
Upper limb		
Fractures	7	6
Wounds	34	12
Bruises	49	12
Lower limb		
Fractures	3	3
Wounds	8	3
Bruises	33	8
Face		
Fractures	107	89
Wounds	200	70
Bruises	252	56
Other head and neck		
Fractures (skull)	1	1
Wounds	32	11
Bruises	29	7
Thorax		
Fractures	2	1
Wounds	8	3
Bruises	34	8
Abdomen		
Wounds	2	1
Bruises	19	5
Unspecified	34	12

This is not dissimilar to the data published by the Home Office describing injuries sustained by police officers in assaults, which is re-presented here [8].

Table 5: Anatomical sites of injury in assaults on police officers

Anatomical site	All assaults	Assaults resulting in serious injury
Face, head, neck	94 (42%)	9 (33%)
Trunk	14 (6%)	2 (8%)
Hands	31 (14%)	5 (21%)
Arms	27 (12%)	0
Legs, knee, foot	25 (11%)	3 (13%)
Multiple areas	35 (15%)	6 (25%)
Total	**226 (100%)**	**24 (100%)**

['Serious' injury for this data is defined by the Police in injury resulting in more than eight days of sick leave].

A review of data from the West Midlands shows injury patterns in police assault victims similar to those found in civilian hospital practise. There was a preponderance of head and neck and upper limb blunt injury [9].

This suggests that there is little difference in the method that civilian assailants fight and inflict blunt injury to both police and civilian victims in violent encounters.

There is however, little data on the distribution of injuries from edged weapon assaults. A study presented later in this thesis describes the distribution of injuries and the relative risks of serious injury or death following stabbing. This is an important factor when determining the desirable protective properties of knife-resistant body armour.

The Weapon Threat

We can learn something of the patterns of weapon use from civilian assault series. Within the UK, there are small regional variations; in Glasgow the use of knives in assaults is slightly more common [11,15,16,17]. It is likely therefore, that the police in Glasgow face a similar risk to the local civilian population and that the risk there differs slightly from other areas of the UK.

We can begin to appreciate the likelihood of sustaining a blunt vs. a penetrating injury in an assault in this country from this review of assault data in civilian victims of violence.

A review of the weapons used in assaults on patients in Lewisham is described in the table below [20]:

Table 6: Weapons used in assaults on patients in Lewisham

Weapon	%
Fists	46
Kicked	17
Weapon not specified	17
Knife	15
Broken Bottle	9
Manhandled	5
Human Bite	2
Unknown	5
Miscellaneous (No Weapon)	9

NOTE: *Many patients sustained more than one type of assault, hence the figures total more than 100%*

A review of assault victims that attended three London Accident and Emergency Departments shows the following distribution of types of weapon used as a function of the locus of assault [17]. This is presented in the following table.

Table7: Assault weapons by locus of incident

Weapon	Job	Home	Street	Pub	U/Grd	Party	Other	Total (%)
Glass	1	1	3	5	0	1	0	11 (6%)
Fist	5	19	37	10	4	1	3	79 (39%)
Feet	1	5	7	0	1	0	1	15 (7%)
Knife	0	2	5	4	0	2	0	13 (7%)
Gun	1	0	1	0	0	0	0	2 (4%)
Multiple	5	3	14	11	0	0	8	41 (20%)
Odd	3	7	23	2	2	3	0	40 (20%)

During the Strathclyde Police initiative Operation "Blade" in 1993 a similar trend was seen: 21% of civilian assault victims had been attacked with knives and other sharp objects, 39% with blunt instruments and 40% had been punched or kicked. Other series show very similar patterns [13].

However, little information regarding the characteristics of assault weapons is available from these civilian series as the weapons do not usually arrive with the victim at hospital.

Knowledge of the length and types of blades most used in an assaults is another important factor in determining the protective properties of body armour for issue to the police.

To appreciate the weapon threat present on the street, we need to look at police data on confiscated weapons.

Norfolk Constabulary's experience is described in the following table. [21]

Table 8: Weapons confiscated by Norfolk Constabulary

Weapon	Frequency
Kitchen Knife (5-9")	33%
Penknife	5%
Flick Knife	3%
Cosh	2%
Dirk	1%
Dagger	5%
Cut Throat Razor	6%
Butterfly	1%
Bayonet	2%
Baseball Bat	1%
Bar	2%
Sword	1%
Survival Knife	2%
Stanley Knife	1%
Sheath	12%
Knuckle Duster	1%
Lock Knife	8%
Machete	2%
Meat Skewer	1%
Screwdriver	3%
Others	9%

Many assaults tend to be carried out with the nearest weapon to hand in the heat of the moment. In domestic disputes, the weapon is most likely to be a kitchen knife or a hand tool. Some assailants will “come prepared” with modified tools or combat knives, however these are a small minority [8,10].

Similarly, criminals caught in the act by police will typically use the nearest available item as a weapon to avoid arrest, for example a car thief might carry and use a screwdriver or another tool of his trade [10].

In Northampton, 33 incidents involving weapons were recorded between January and June 1996. These incidents are presented in the following table[8].

Table 9: Weapons used in assaults on police officers

Weapon	Number
Edged Weapons	17
Dog	1
Club	3
Shoe	1
Cigar lighter	1
Broken bottle	4
Beer can	1
Hammer	4
Firearms	1

Data on assault patterns has been presented for both police and civilian populations. Patterns of wounding are similar for both. The majority of injuries occur after blunt injury, most injuries from this mode of assault are to the face, head, neck and limbs. Most of these injuries are not ‘serious’. Body armour will offer no protection against this threat.

There are no series describing serious penetrating injury to police officers. Data from civilian series do not accurately describe the severity or location of penetrating wounds. This information is necessary if we are to understand the threat of penetrating injury to the police. A retrospective review of 500 civilian penetrating injuries is presented later. This allows us to identify the anatomical risk and hence consider which parts of the human body need protection and to what degree.

It is now appropriate to describe the physical properties of modern body armour. It will be then be possible to demonstrate how to make the best use of modern body armour technology in providing the police with the most appropriate and suitable protective garment, reflecting the best balance between wearability and protection.

PART 5: THE PHYSICAL PROPERTIES OF MODERN BODY ARMOUR

Introduction

A discussion of the materials and physical properties of modern armour is required. This is central to understanding the spectrum of protective properties of different armour types and the implications (in terms of wearability) of strengthening armour. This will also provide the tools for understanding manufacturing and testing standards.

Materials

For more than twenty years para-aramid woven fibres have been the mainstay of soft body armour. This material evolved as a derivative from research into tyre manufacture. Dupont have marketed this woven fibre as Kevlar ®. It has a high tensile strength, low specific weight and is non-flammable. More recently, Kevlar ® has been combined with other materials in composites for other personal protection equipment including military helmets and sports protective equipment.

As a projectile strikes the woven fibres, its energy is dissipated and dispersed through the fibres until it is stopped.

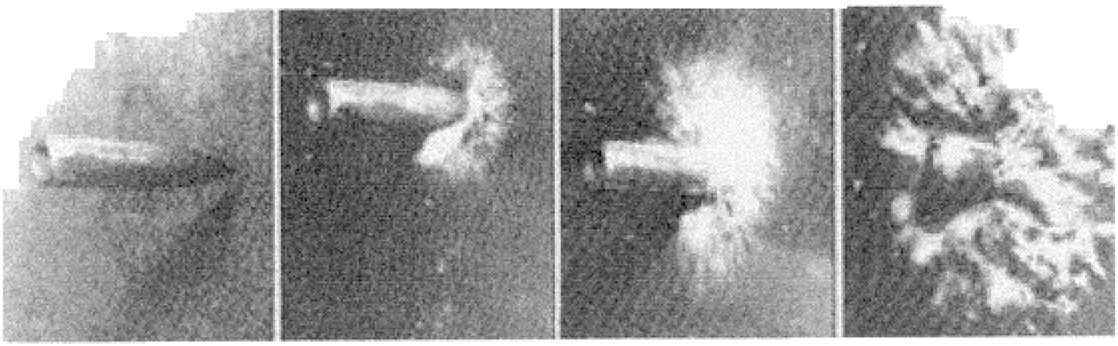


Figure 10: A bullet arrested by body armour

(reproduced from Phoenix systems website)

Unfortunately, Kevlar ® fibre can be cut by a knife and therefore, unless it is combined with another physical barrier, it is not stab-proof.

The protective properties of a Kevlar ® garment can be manipulated by altering the weave, the number of layers, and the orientation of the layers.

To improve the knife-resistant properties of Kevlar ®-based armour, manufacturers have combined other materials with the aramid fibres. These include metal plates, ceramic plates, cable weave and chain mail. While these materials do improve knife protection, they also decrease the flexibility, increase the weight and ultimately adversely affect the wearability of the garment.

Stab resistant armour materials

The penetrative power of knives is largely a product of the energy density achieved at the tip of the knife. A relatively blunt knife might have a tip radius of 0.25 mm. The energy of an average human stab attempt is approximately 40 Joules. This gives an energy density at the tip of more than 200 J/mm^2. This can be compared to 80 J/mm^2 for a 7.62mm rifle bullet or 11 J/mm^2 for a 9mm bullet. Consequently textile armours which are efficient at stopping bullets often offer inadequate protection against knife attacks [22].

Penetration of a blade through a target material occurs in three stages: indentation, perforation and penetration. The force resisting indentation is a function of knife sharpness and the coefficient of friction between the knife and the target. Commonly used textile armours offer little resistance to indentation. Tightly woven fibres appear to be a little better in this respect [22].

Perforation follows indentation as the armour fails. In metal armour 'petalling' occurs, in composite armours this process occurs as the plates split [22].

Penetration occurs as the perforation is widened and the blade passes through. This process can be arrested by materials that resist hole enlargement (cutting resistance) or by increasing the frictional interference between the blade and the armour material [22].

The penetrative nature of the knife is dependant upon its shape and sharpness. A sharp knife requires considerably less force as the tip energy is over a smaller area. Thinner blades penetrate easily but are more susceptible to frictional effects and may be prone to buckling failure [22].

Heavy section knives are easier to defeat with soft armours as their large cross sectional area means that a large perforation is required and the contact area for sliding resistance is great. However, the greater resistance to buckling makes heavy knives more effective against hard armours [22].

Modern knife-resistant systems

Hard metal or composite plates are the simplest method of providing stab resistance. These materials are sufficiently hard to defeat knives during the indentation stage and present a large resistance to penetration should perforation occur [22].

Most fibres offer resistance to cutting: it is important that the knife is forced to cut through the fibres rather than part the weave. The matrix must resist fibre movement. The addition of cut-resistant fibres such as tungsten wires within the composites has been shown to be more effective in this respect [22].

Titanium and ceramic systems are hard enough to offer good protection but are clearly inflexible and difficult to wear. Armadillo type (overlapping and sliding) joints of hard plates in body armour systems have been trialled in an attempt to facilitate the wearer's body movement [22].

Textile armour is the most flexible and wearable of all armours. Current textile armour offers a low level of knife protection. Closely woven fibres (silk and linen) were used in historical pre-Christian armour systems and were effective in reducing injury from edged weapons. Closely woven fabrics force the knife to cut fibres rather than forcing the weave apart. At present, the cost of close-weaving Kevlar ® systems is prohibitively expensive [22].

Standards

Standards for body armour have been determined by different agencies and manufacturers to describe the degree of protection offered against both ballistic projectiles and the passage of blades. The definition of standards allows armour systems to be built to validated specifications.

The protective properties of body armour are quantified on test rigs. A test sample of armour is mounted on a clay block which was historically considered to represent the physical properties of the human trunk [23,24]. The clay is standardised in terms of its consistency, moisture content and temperature. This allows tests to be carried out in the same standard conditions at different testing facilities and minimises discrepancies between centres [23].

To determine the degree of ballistic protection, a bullet is fired into a sample of body armour mounted on a clay block. The depth of the crater in the clay behind the sample, after the arrest of the bullet is measured. The depth of this crater is referred to as the backface deformation and is described in millimetres [23].

Figure 11: Indentation into clay after the bullet is arrested by the armour

The American National Institute of Justice (NIJ) classified ammunition into different threat levels by weight and velocity. Body armour could then be tested for protection against ammunition in each group. Modern ballistic armour is now rated in terms of its protection against a specific ballistic threat. This classification has been universally adopted [24].

Table10: NIJ ballistic testing

Armour type (HG)	Test round	Test ammunition	Nominal bullet mass (grams)	Minimum required bullet velocity (ft/s)
I	1	38 special	10.2	850
		RN lead	158	850
	2	22 LRHV	2.6	1050
		Lead	40	1050
IIA	1	357 Magnum	10.2	1250
		JSP	158	1250
	2	9 mm	8.0	1090
		FMJ	124	1090
II	1	357 Magnum	10.2	1395
		JSP	158	1395
	2	9 mm	8.0	1175
		FMJ	124	1175
IIIA	1	44 Magnum	15.55	1400
		Lead SWC	240	1400
	2	9 mm	8.0	1400
		FMJ	124	1400
III		7.62 mm (308 Winchester) FMJ	9.7 150	2750 2750
IV		30-06 Armour piercing	10.8 166	2850 2850

For routine police work in America, protection against HG I ammunition is usually considered adequate [23]. For police officers working in high risk environments facing higher velocity ammunition, protection to HG IIA or higher is more appropriate. The degree of protection required against ballistic threats needs to be determined by a local risk assessment of that particular policing environment.

Knife resistance

To measure the knife resistant properties of body armour, a test blade is delivered to the mounted sample at a given energy by one of three methods: air cannon, lever arm or drop tower. The depth of blade penetration into clay beyond the sample is measured.

The Police Scientific Development Branch of the Home Office employ an air cannon [25].

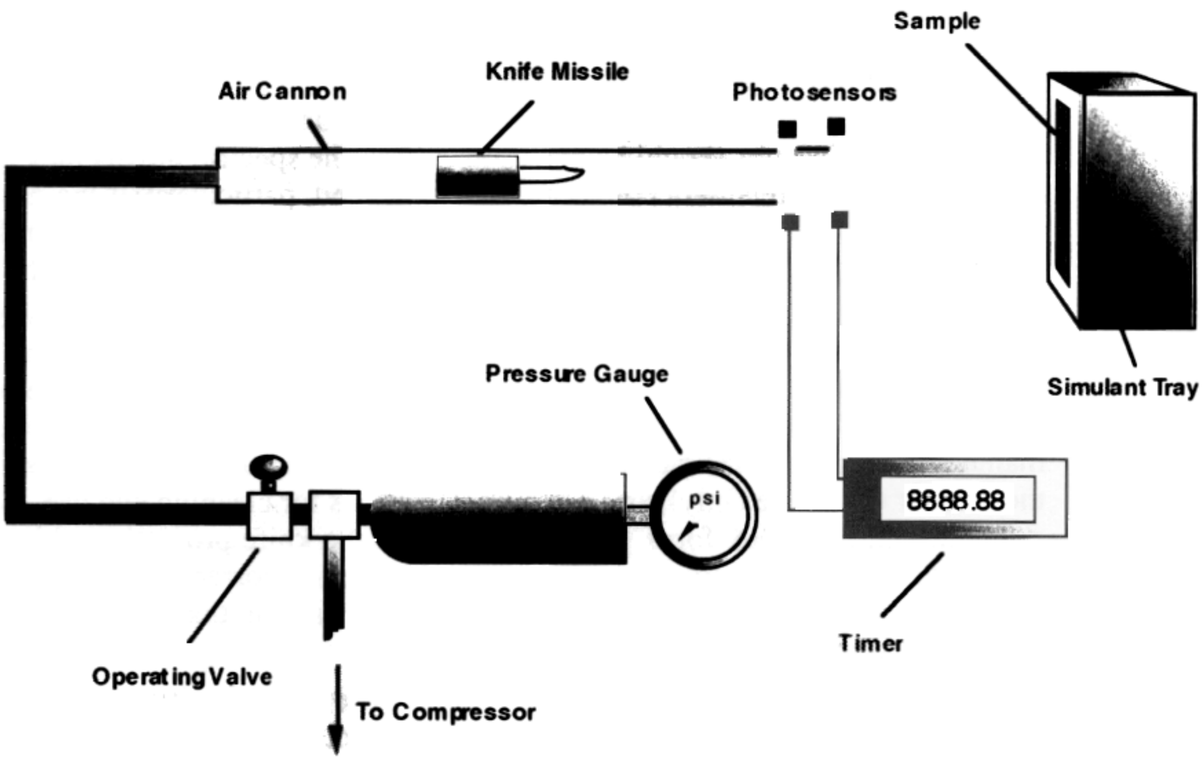


Figure 12: PSDB test rig

(reproduced from PSDB stab resistant body armour test procedure)

The depth of the blade indentation into the clay is measured if it penetrates the armour sample.

Figure 13: Blade penetration through armour into clay

At the Royal Military College of Science (Cranwell University) a drop tower is used to deliver the blade to the sample. The depth of knife penetration is measured in the same way.

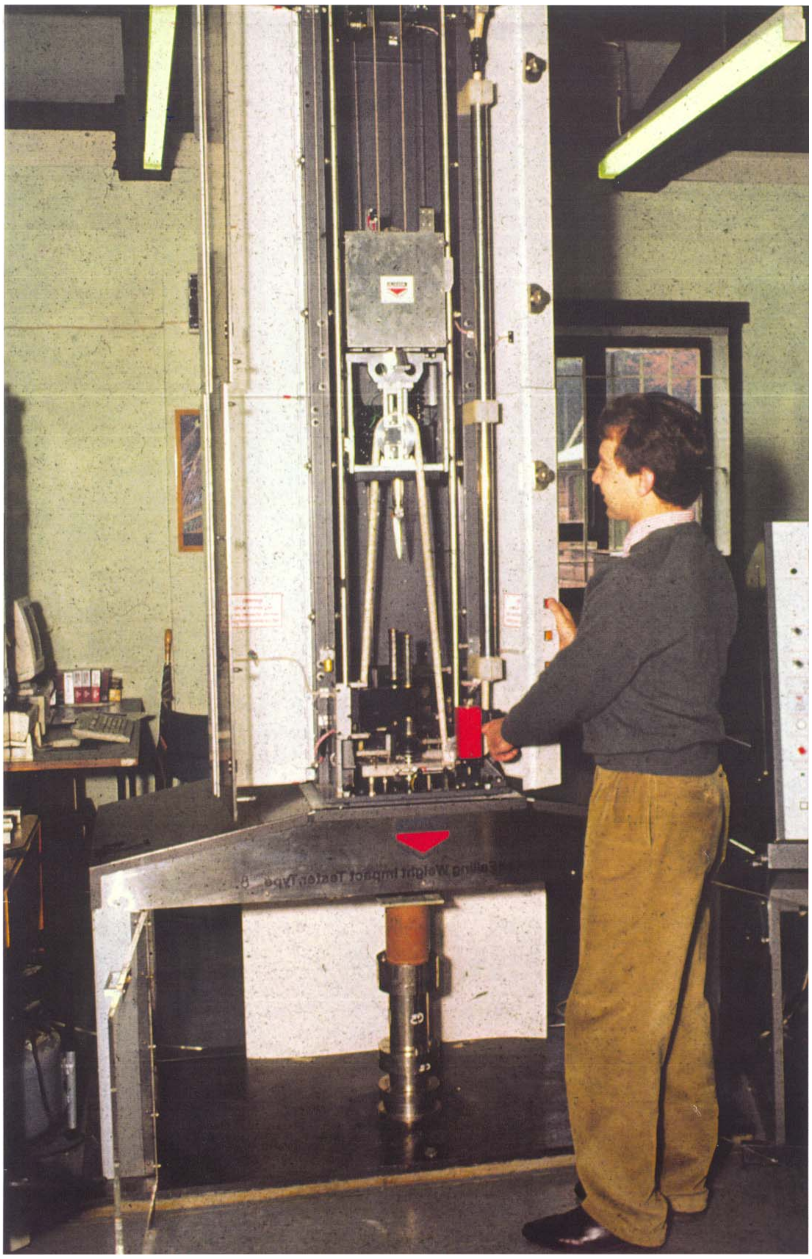


Figure 14: Drop tower at Cranfield University

(photograph provided by RMCS)

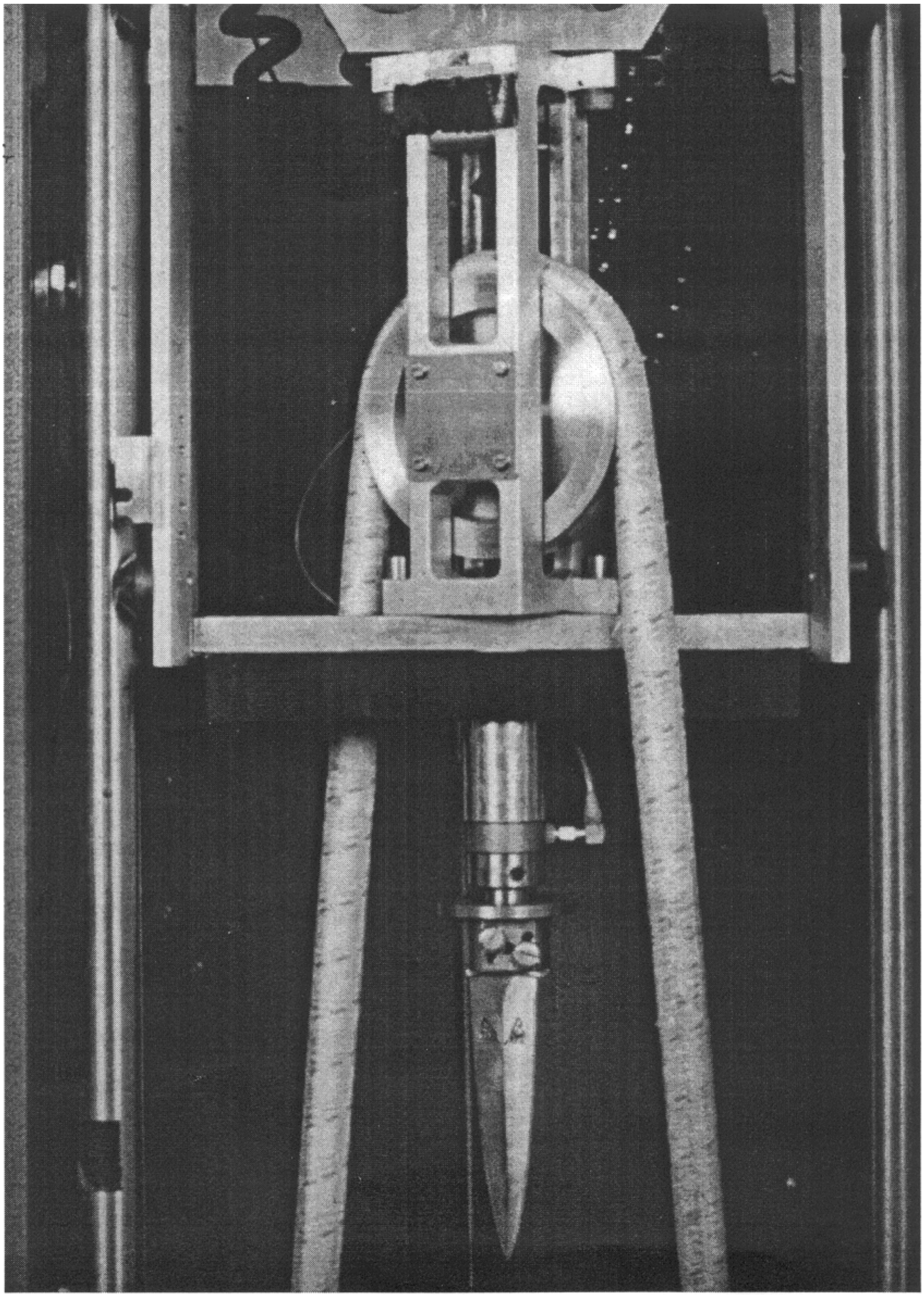


Figure 15: Accelerating mechanism for a test blade on the drop tower

(photograph provided by RMCS)

Knife resistance testing: current test procedures

PSDB test [22,25]

An air cannon is employed to propel knives at velocities of up to 20 ms^{-1}. The knives are held in sabots (rigid handles mounted on the test rig). The total weight of the projectile is 400gm. The delivered energy is calculated for each test. A new blade is used for each firing. The muzzle velocity of the projectile is measured by optical gates and the test panel is situated 75 cm from the muzzle. The target is rigidly held against a plastalina block. After the test, penetration is measured directly as the blade is held in the target panel (if penetration has occurred). Penetration is plotted as a function of impact energy and must lie within a defined envelope. Failure of the armour is said to occur if the knife penetrates more than 5 mm into the clay.

The armour is also subjected to an angled attack performed by hand. This is designed to test armours that use overlapping plates. This part of the test is operator-dependent.

Metropolitan police test [22]

A swinging lever arm propels a sharp triangular sectioned spigot into the armour sample supported on a plastalina block. This is propelled at the target at an energy of 42 Joules. Knife blade penetration into the clay is measured. Armour fails if the blade penetrates more than 20mm into clay.

H P White test (American) [22]

This is a drop weight test which uses an ice pick as the threat. 213 Joules is generated by using a 40.5 lb weight. The test sample is supported on a plastalina block. The impact must not penetrate the armour or cause a backface deformity of more than 44mm.

Swiss and German police tests [22]

The test blade is a double-edged commando style knife. This is dropped onto the armour to give an impact energy of 35 Joules with the total drop mass being 2.6 kg. Failure is defined as blade penetration of more than 20 mm into the backing or a blunt trauma (backface deformity) of more than 40 mm. The German test uses a greased blade sharpened at 20^0 on each face.

Accepting and Applying Standards

The Police Scientific Development Branch of the Home Office have adopted a 25 mm standard for ballistic trauma. This means that the depth of the crater in the clay behind a body armour test sample must not be deeper than 25 mm for a given type of ammunition. This was an arbitrary figure reportedly based on early animal experiments, the original source of this standard can no longer be traced [26].

PSDB have accepted up to 5 mm of backface penetration into clay for the knife standard. This is for test blades delivering 42 Joules of energy. This figure has been shown to be representative of the 'average' male stabbing attempt, determined on human stab test rigs. This 5 mm standard was reportedly adopted on the advice of a pathologist who estimated that the large vessels of the chest wall are protected by approximately ½ inch (12.7 mm) of soft tissue [26].

The American National Institute of Justice (NIJ) accepted a much lower standard for ballistic protection; this allows for 44 mm of backface deformity, (the depth of permissible indentation into the backing clay is nearly twice as much as the PSDB standard). NIJ will accept 20 mm of knife penetration into the clay for knife resistant armours [27].

American body armour has been made to the NIJ standard for over twenty years. This standard has also become widely accepted in Europe. In the absence of national and indeed international agreement, the Metropolitan Police adopted this standard for the 'Metvest' in 1995 [28]. Clearly, this standard allows a far greater transmission of energy and is a lower standard than that selected by PSDB. The track record and experience with armour made to this standard in America has been described.

The Centre for Ballistic Analysis in America claims that an even greater backface deformity can still be safe. This claim is based on a retrospective analysis of 425 actual police shooting incidents. These incidents were reproduced using the recovered weapons, fired at the same distance and angle to target (NIJ standard body armour mounted on a clay model). The results, in terms of backface deformity, were correlated to the description of injuries sustained by the victims [23]. Backface deformities greater than the 44 mm were inflicted on these models and reportedly corresponded with almost 'negligible' actual injuries sustained by the shooting victims. This report does not mention to what degree the victims were incapacitated after injury or how vulnerable they were to a second attack once they had been hit [23].

The Metropolitan Police have defined a standard of 20 mm backface knife penetration for knife-resistant armour [28]. This was reportedly adopted from German work which argues that the large vessels of the chest wall, heart and pleural cavities are protected to this depth by soft tissue. In their view the only exception to this is the presence of the internal mammary blood arteries (which run vertically down both sides of the sternum) and are more superficial. The original source of this is no longer traceable [26].

The European Union are at present debating these standards with a view to adopting and recommending a single European standard. These standards are likely to approximate those set by NIJ. The Home Office has not yet decided whether the PSDB standard will continue to be recommended to police forces in this country if a lower EU standard is imposed.

Testing Issues

Clay is used for both ballistic and knife testing. It is now accepted that clay is a poor simulant of the physical properties of the human body. It is not elastic and takes no account of the dynamics of the human body. There are therefore worrying uncertainties concerning the accuracy of model simulation when attempting to ascertain the potential injury to human tissue. The clay model does not take into account the differences in resistance provided by hard and soft areas such as the spine, bony rib cage and soft abdomen. Other simulants have been developed, but none has gained universal acceptance.

The US army developed a procedure for predicting the risk of lethality as a function of backface deformity, it is based on old animal experimentation and therefore its validity is very questionable, even after mathematical adjustment to compensate for human anatomical differences. The methods of this 'mathematical adjustment' are not available. [23,29]. Animal testing can, however, predict patterns of injury from arrested ballistic trauma [29].

Ballistic testing is reproducible between centres: the consistency and temperature of the clay can be standardised, the ammunition can be made and delivered to the target in a specified manner. Bullet velocity can be measured and the ammunition can be made to an exact specification.

It is not possible to correlate a given ballistic standard with injury potential in actual shootings. The protection offered by a given standard can only be determined by retrospective analysis of 'saves' in the operational arena. Such is the case for the NIJ standard which has been applied in America for over 20 years [4]. A higher standard (one which permits less backface deformity) can only be assumed to offer better protection for the wearer.

Ballistic testing

The NIJ states that the maximum allowable deformation of the clay backing material permitted by the 44 mm standard was determined through an 'extensive series of ballistic gelatin measurements and animal experiments conducted by a team of medical experts. This limit aims to ensure protection from blunt trauma arising from an impact occurring over vital locations' [29].

It is, however, far easier to reproduce ballistic testing than knife attacks. Knife testing varies between centres. Different knives are used, and the sharpness of the tip is not always specified.

When attempting to predict the injury potential after an arrested ballistic strike, there are several critical physical factors that must be considered:

1. A greater transfer of energy occurs when the body armour is mounted on a firm surface [27]. This leads one to suppose that more injury is likely when the armour is struck by a bullet over the victim's ribs than over the relatively soft abdomen.

2. The distance between the armour and the wearer's skin. If an undergarment is worn, or if the armour is not flush against the body at the point of impact, then there will be some additional "dead space" before backface deformity will begin to impinge on the tissues of the body wall. The air in this space will also provide a medium for the dissipation of some of the transferred energy.

Knife testing

For knife resistance standards the problems are far more complex. The mechanism of injury is very different. We need to define how much penetration of the human body is permissible if a blade breaches the armour. For injury to occur in a knife assault, a weapon has to be delivered to the target. This action has three components: the assailant, the weapon and the method of delivery to the target.

The assailant and method of delivery

To date, knife testing has employed one of several delivery systems: drop tower, lever arm or air cannon. This is meant to replicate the assailant thrusting a knife at the target. For testing to be meaningful, this action must be shown to approximate a 'worse case scenario' human stabbing attempt. It must also replicate the mechanics of a human stab attempt.

The weapon

Testing must utilise blades that represent the most deadly knives and worst threat to police officers. This information will become available by examining confiscated knives present as a weapon threat to the police. The geometry and sharpness of these blades needs to be considered.

Once these factors have been determined, it will be necessary to consider how much penetration into the human body is permissible. These will be the elements used in defining a knife resistance body armour standard. These issues will be addressed later in this paper.

At present, there is no model that accurately simulates the dynamics of human stabbing attempts. There are many variables that should be taken into account, including:

- the complexities of the mechanics of trunk and upper limb movement during stabbing
- variation of assailant stature and weight that would influence the kinetic energy
- variation in assailant technique (overhand, underhand and angled approach to target)
- assailant stabbing tactics (trained or opportunist, random slash or targeted force)
- blade geometry and sharpness
- distance from assailant to target
- physical properties of the target (chest wall vs. soft abdomen)
- fixed vs. mobile targets

In testing, knife penetration through armour is dependant upon blade geometry and the stabbing technique. Backing material and impact angle have only a minimal effect on penetration. Current knife testing methods present further difficulties in assault simulation:

1. For stabbing simulation, test rigs use a single shot “energy dump”. It is difficult to correlate current test methods to the reality of stabbing and slashing wounds, that is, the technique. It is similarly difficult to estimate the energy imparted by human attempts at stabbing. There is tremendous unpredictability of a blade’s ability to penetrate previously impervious body armour when the technique of the assault is modified. Blades tend to penetrate much deeper when the initial force of the stab is followed through.

2. It is impossible to test every type of knife that might be used in a real attack. In testing, we need to consider and assess the weapons that are prevalent on the street. Typically two or three blade types are used in a series of tests. However, there is an increasing number of injuries inflicted by sharpened screwdrivers and other home-made and opportune sharp implements.

3. In test rigs, the blade tends to bounce off the armour when it is mounted over soft backing. There is less bounce when the armour samples are mounted over hard backing, however the initial penetration is greater [30]. This has implications for assaults on different areas of the body (rigid chest wall vs soft abdomen).

4. Machete type attacks are difficult to simulate as they largely impart blunt energy transfer.

Blade geometry and stabbing technique are the most important factors determining penetration through armour. Current testing methodologies do not accurately simulate the reality of most actual knife assaults.

PART 6: INJURY POTENTIAL

Introduction

The purpose of body armour is to prevent or reduce the potential for injury. In this discussion, the potential for injury from arrested ballistic strikes and penetrating edged weapons will be reviewed. It is important to understand these issues and be able to begin to quantify injury and the risk of death after injury. In this way it becomes possible to discuss, and have a frame of reference for, the 'seriousness' of injury.

Arrested Ballistic Blunt Trauma

In arrested ballistic strikes, the body armour is struck by a missile and its kinetic energy ($^1/_2\ mv^2$) is imparted to the armour. This energy is typically described in Joules. This energy is partially dissipated in sound, heat, deformation of the missile and deformation of the armour. Some is lost in the "dead space" between the armour and the skin of the victim. The remaining energy will continue on and compress the body wall, some will continue on into the body. This is the same energy that causes the backface deformity in the clay on test rigs. As this energy is transferred to the body it must traverse the skin, subcutaneous fat layer and muscle. Injuries from this type of trauma are caused by the transfer of the remaining energy to the internal organs as it is dissipated inside the body.

Strikes over the bony chest wall will encounter bone (a hard backing material). The remaining energy is then likely to encounter the lungs.

A strike over the soft abdomen will not encounter bone (a soft backing material). After skin, fat and muscle the remaining energy will encounter the internal organs.

Animal experiments have been useful in determining the nature of injuries that will be inflicted by this type of trauma, but have little role in determining the forces required to produce the same effects in human subjects [29,31]. For arrested ballistic trauma, researchers have determined that the lung is the most susceptible organ to the imparted energy dump frequently resulting in pulmonary contusions [29,32].

Penetrating Knife Injury

In penetrating knife injury, the body wall is breached and the nature and extent of damage to the internal organs is determined by the passage of the blade.

The severity of stab wounds is determined by the location, angle and depth of blade penetration. Important considerations in penetrating injury include the type of weapon used (knife length, shape, straight or serrated), and the manner and technique of assault (overhand vs. underhand).

The gender of the assailant may have some importance: women tend to stab "overhand" and men "underhand" [33]. Overhand stabbings tend to generate higher energies. This can be up to 100 Joules [34]. An 'average' stab is generally considered to be 42 Joules on a test rig.

Trained assailants will approach a victim from behind and use one arm to pull the victim's body onto the blade, thereby increasing the amount of force applied, the penetration and the likelihood of fatal injury. Their technique is not that of the single energy dump employed on modern testing rigs, but rather the initial thrust is followed by a further push into the body.

Most of the resistance to the passage of a blade is from the skin and subcutaneous tissues. After breaching skin the next layer of resistance is provided by muscle[31]. Therefore the victim's physical build is of importance in susceptibility to penetrating injury. Relatively obese or muscular individuals will be slightly better protected from penetrating injury.

The force required to cause a stab wound [31]

1. The most important factor is the sharpness of the tip of the weapon. If the point is sharp, penetration is easy and once through the skin, the sharpness of the rest of the knife-edge is much less important.
2. The faster the stabbing movement, the easier it is to penetrate the skin. A rapid lunge is much more effective than a slow push.
3. Once the knife point is through the skin, the rest of the weapon follows, with almost no additional force required. The skin indents before penetration and acts as a reservoir of energy, allowing the knife almost to 'fall' into the body when the skin is breached - assuming that no bone lies underneath.
4. Skin is the most resistant tissue to a knife, excepting bone and cartilage. However, a sharp knife can penetrate these, especially youthful rib and costal-cartilage, given sufficient force.
5. Very little force is required to push a sharp knife through the skin, especially where the latter is stretched across ribs, as in the chest. Pressure from a little finger alone is enough to penetrate a really sharp-tipped knife into the thoracic cavity. The heart and other internal organs are far less resistant than skin.

To further understand the injury potential in knife attacks, we need to be aware of the anatomical and physiological variables which will influence the severity of penetrating injury.

Anatomical variables

Individual body dimensions are influenced by:

1. **Skin thickness** – this varies between individuals and body areas.

2. **Obesity -** the depth of the subcutaneous fat layer beneath the skin.

3. **Muscular thickness** - the depth of the muscular layer, this is influenced by fitness, gender and age.

4. **Gender** – the presence of breasts in the female (the dimensions of which vary enormously) provides additional protection from both blunt and penetrating injury.

5. **Age** - the older the individual, the less the compliance (compressibility) of tissues, especially bone. This means that in older individuals, bones tend to snap rather than bend when struck by a blunt force.

6. **Dimensions** – height and weight.

7. **Accessibility of the internal organs** - the potential for penetrating injury to the internal organs depends in part on their accessibility.

A Medline literature search did not reveal any previous anthropometric work on the depth of the major organs from the skin. There exists material on the external dimensions and proportions of external body dimensions, however no published data were found describing the internal dimensions and ratios within the body. Existing standards for body armour have been determined by asking pathologists' opinions on the likely degree of cover afforded by the thickness of the human trunk [25,26]. To explore the accessibility of organs, a CT study, presented later, provides this data on a cohort of 20 – 40 year olds. This population is representative of the majority of serving police officers.

Physiological considerations

The following physiological factors need to be considered:

Muscle tone - In an unsuspecting victim, muscle tone will be far less (muscles are relaxed) than in an individual who is forewarned of impending assault (muscles are tensed). Tensed muscles will afford more resistance to both the passage of a blade and to the transfer of blunt trauma energy.

State of respiration - At the end of expiration (letting all the air out), the diaphragm will ascend up to the level of the fourth rib. The upper abdominal organs will follow and thus be present in the lower chest at this stage of the breathing cycle, particularly the stomach and the liver. Conversely, at the end of inspiration (taking a deep breath), the diaphragm will descend to the level of the tenth rib as the lungs expand. These organs will thus leave the bony chest cavity. The position of the upper abdominal organs at the instant of assault (both blunt and penetrating), will therefore have an influence on the nature of injury. There will also be some movement of the heart and great vessels within the chest with breathing movements.

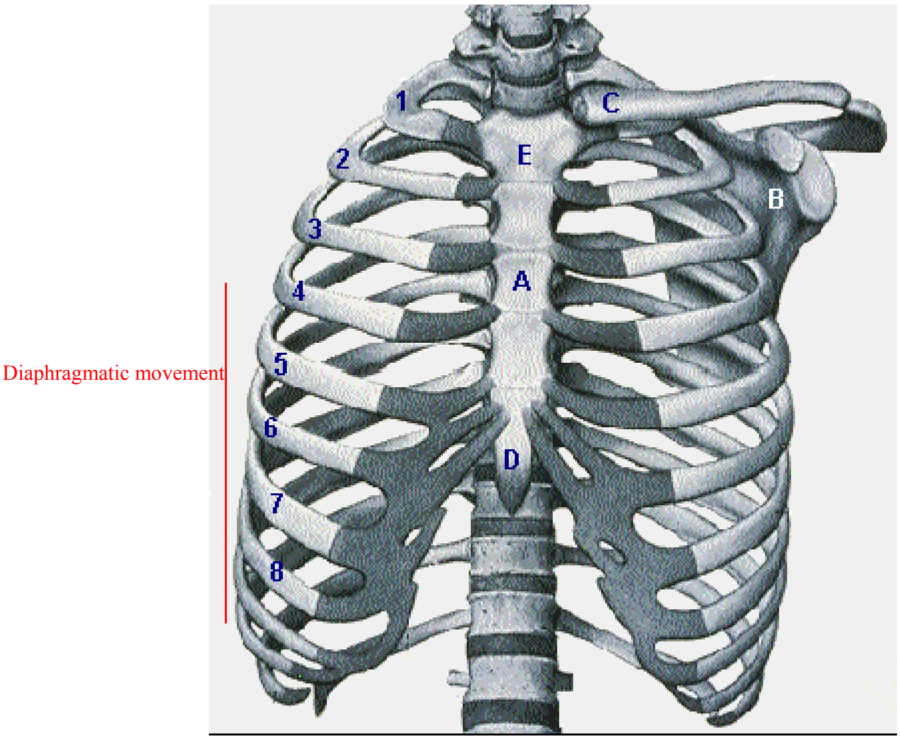


Figure 16: Diaphragmatic excursion with the breathing cycle

(reproduced form 'Dr Schueler's CD ROM')

'Valsalva' - a forewarned victim may take a deep breath and hold it just prior to the instant of impact. The chest is expanded and the glottis (throat) is held closed. This, in effect, is a closed system under positive pressure. An impact will cause a sudden increase in pressure within this closed system and the lungs may burst. This is recognised as a 'closed bag' injury and is sometimes seen in the victims of steering wheel injuries from road traffic accidents [33].

State of the gastrointestinal system - after a meal, the stomach and intestines are distended. This will cause some splinting of the diaphragm, that is, there will be less movement during the breathing cycle. The distended gut is more susceptible to rupture after blunt trauma than in the non-distended state.

Injury Scoring Systems

When describing and considering the injury potential of assault, it is useful to have a system that can quantify the severity of injury and estimate the risk of death after wounding. Trauma scoring can be applied in this respect.

Trauma scoring was introduced in 1964 to provide ambulance personnel delivering emergency medical care with a scientific tool to assess the severity of trauma, so that the patient could be delivered to the most appropriate medical facility.

This tool evolved into a system that provides the physician with the ability to predict a trauma patient's outcome in terms of probability of survival, by measuring predetermined variables and assigning them a score. Several systems exist, and are described. Each uses either physiological data (how the patient physiologically responds to the injury), anatomical injury data (the actual injuries) or a combination of both to determine the severity, and hence risk of mortality after injury. Some variables are more important than others and are mathematically weighted [35].

Quantifying Injury and Predicting Outcome after Injury

There are two systems that are widely used to quantify injury and predict outcome after injury. Both systems have their limitations.

TRISS methodology

The Abbreviated Injury Score (AIS), Injury Severity Scale (ISS) and Trauma Injury Severity Scale (TRISS) methodology comprises a mathematically sound system for the analysis of injuries and injured patients. This system is used to predict the probability of survival from injury. In this way, populations of injured patients treated in different hospitals can be compared and the quality of care in each institution can be rated by identifying unexpected outcomes in terms of mortality [36].

The AIS was developed to quantify injury after road accidents. AIS allocates specific codes to specific injuries and a severity score between 1 and 6 (1 being minor and 6 being unsurvivable). This evolved into the concept of a whole body score or Injury Severity Score (ISS) being derived from the three highest individual AIS scores. The ISS is still the accepted international standard for trauma scoring. The three highest AIS scores in different body regions are squared and then added together to provide the ISS [37,38].

ISS considers the body to comprise six regions: head/neck, face, chest, abdominal or pelvic contents, extremities or pelvic girdle and external (skin). Possible ISS scores range from 1 to 75. Patients with an ISS score of 16 or more have at least a 10% risk of mortality and are defined as major trauma victims.

The ISS (made up of the sum of the squares of the highest AIS scores in the top scoring three anatomical regions) relates to anatomical injury in isolation. If we incorporate the individual patient's age and physiological response to injury, the probability of survival (P_s) can be calculated more accurately. For this we need to incorporate weighted scores for conscious level, systolic blood pressure and respiratory rate. These variables give us the Revised Trauma Score (RTS). Both the RTS and ISS are entered into a mathematical formula to calculate the mathematical probability of survival (P_s).

[The probability of survival Ps = $1/(1+e^{-b})$ where b represents the weighted coefficients for blunt or penetrating trauma and RTS and ISS values.]

Patients with a P_s of < 0.5 who survive are therefore unexpected survivors and those with a P_s of > 0.5 who die are unexpected deaths. This system provides a very useful hospital audit tool [39,40].

When defining the risk of injury and death to wearers of body armour, ISS alone can be applied to estimate the probability of survival, as hypothetical physiological data is of little value. Use of ISS will provide the risk of death in broad terms of less than or greater than 10% or less than or greater than 50%.

An ISS score of greater than 15 is classified as major trauma and correlates with a mortality of greater than 10%. Commonly, a victim may sustain several life-threatening injuries from a single assault and then the ISS score and probability of death will be higher [35].

More recent scoring systems claim to be more accurate. The ASCOT system (a severity characterisation of trauma) is essentially the TRISS system with modifications to allow for a more precise prediction for patient outcome for penetrating injured patients in particular. It incorporates physiological and anatomical injury data in a more comprehensive manner than TRISS [41]. Even though it is reported to be slightly more accurate than TRISS methodology [42], it has not replaced it as the tool for national trauma scoring in this country (UK Trauma Audit and Research Network). This is perhaps due to it being more time-consuming to complete and calculate [42].

Red Cross classification

The Red Cross Classification of War Wounds is another system that is used to classify the severity of war wounds. It cannot be used to accurately predict the likelihood of survival after injury. It is used as a benchmark to describe the severity of wounds so that surgical management can be compared between centres. It is not easily applicable to the discussion of wounding in civilian assaults [43].

The new injury severity score (NISS)

This more recent system, uses the sum of the squares of the AIS scores of each of a patient's most severe AIS injuries, regardless of the body region in which they occur. It was found that this was easier to calculate than the original ISS system and was more predicative of survival. This system will be of benefit in calculating severity of injury in multiply injured patients [44].

For the purposes of the discussion and description of injuries in the next section, injuries can only be described singly in terms of their AIS score. The TRISS and ASCOT systems cannot be applied as we are talking in general terms and not about specific patients with unique physiological responses. The NISS system is also of little value to this discussion as it is impossible to predict multiple injuries in this context.

In determining the severity and threat of wounds, TRISS scoring offers the best of these systems and will be used in the description of injuries in the next section.

Injuries Caused by Stabbing

Figure 17: Multiple stab wounds to the chest

(reproduced from Dr Schueler's CD ROM)

In civilian practice, most stabbings are to the trunk: these involve the chest (33%), abdomen (57%), or both chest and abdomen (10%) [45]. Fatal stabbings tend to involve the left chest[34]. Most chest stabbings strike the left anterior chest wall, presumably by right-handed confrontational assailants[46]. The distribution of penetrating wounds in a civilian population is presented in more detail later.

Deaths from stabbings result from haemorrhage, disruption of normal breathing mechanics, and as a late event, by sepsis.

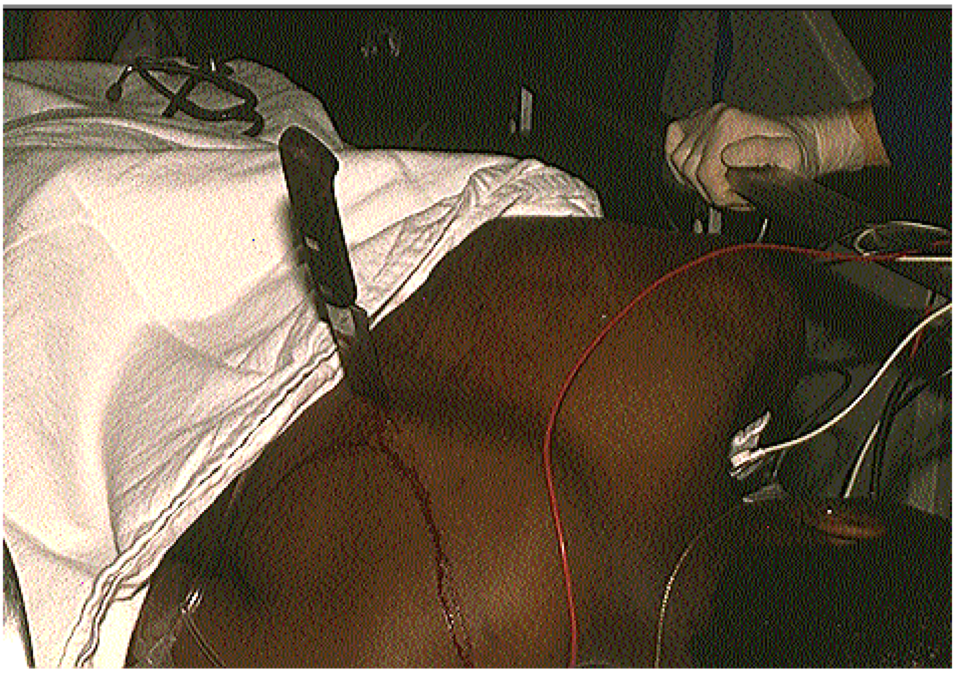


Figure 18: A minority of chest stabbings are to the back

Common injuries seen in stabbing victims are described here. Where possible the approximate risk of death is presented in terms of ISS.

Pneumothorax

This is a condition caused by the abnormal introduction of air into the chest cavity (leading to a collapsed lung). This may occur due to a breach of the chest wall or via a tear of the lung itself. A simple breach of the chest wall is enough to cause this condition. The depth of penetration required to cause a pneumothorax by stabbing will be determined by the depth of the victim's musculature and body fat at the point of wounding.

A pneumothorax may be *simple* (partially collapsed lung) or it may progress into a *tension* pneumothorax. In the latter, the chest wall wound or lung tear acts as a flap valve, so that with every breath, more air is sucked into the chest cavity further collapsing the lung. Eventually the unequal pressures in the chest will cause the heart and great vessels to be pushed to one side until kinking of major vessels occurs. At this point blood cannot enter or leave the heart and death rapidly follows in the absence of urgent medical attention.

The Injury Severity Score (ISS) for a simple pneumothorax is 9 and for a tension pneumothorax 25. Both of these life-threatening conditions require urgent medical attention. Treatment is directed towards draining off the air thereby restoring the mechanics of breathing.

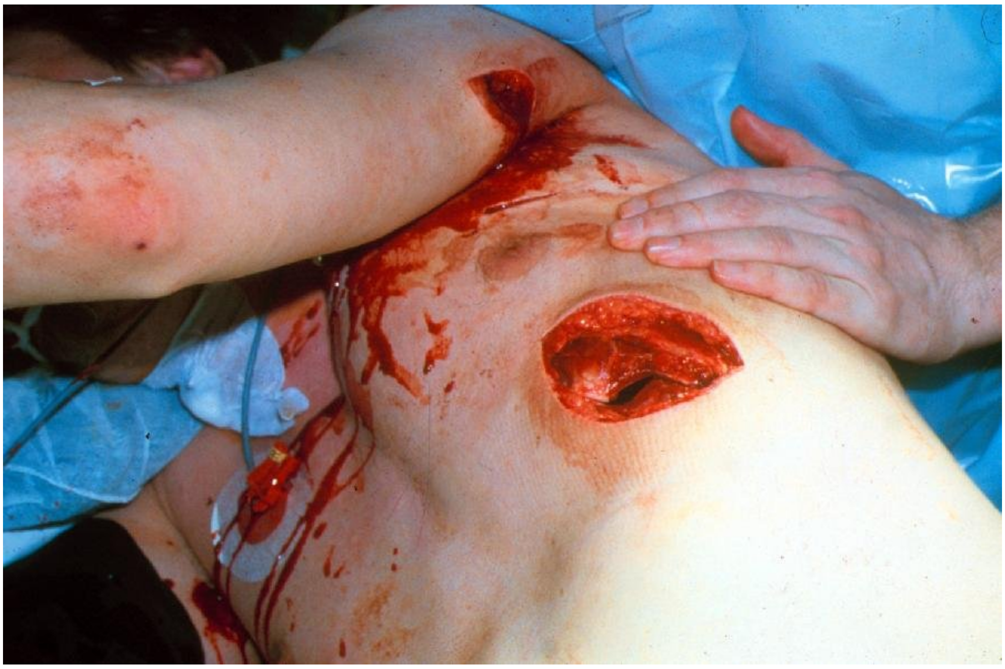


Figure 19: An open chest stab wound

Haemothorax

A haemothorax is a collection of blood within the chest cavity. This can result from bleeding following penetrating chest trauma. The bleeding can be from large blood vessels in the chest wall (intercostal arteries, internal thoracic artery), or following injury to the internal organs in the chest.

The mechanics of breathing may become compromised by the increasing pressure within the affected side of the chest (similar to pneumothorax). In addition, the blood loss may be large enough to cause hypovolaemic circulatory shock.

This condition also requires urgent medical attention which is directed towards restoring the normal mechanics of breathing by draining the blood, and replacing the lost blood volume by transfusion. Massive blood loss into the chest will require open chest surgery.

The ISS for a simple haemothorax is 9.

Both of the above conditions can co-exist: haemopneumothorax. The ISS for this is 25.

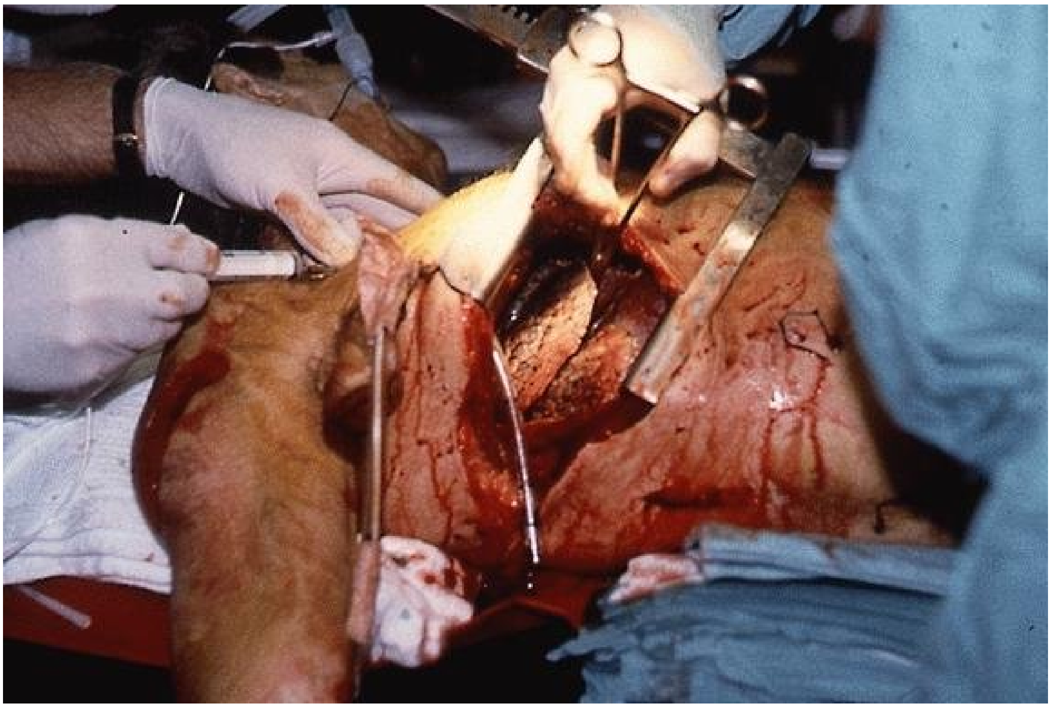


Figure 20: Emergency thoracotomy following a penetrating stab wound

Aortic injury

The aorta lies on the internal chest wall just to the left of the spine. Should an assailant's knife breach the aorta, death from blood loss would be inevitable for the majority. Some will survive to hospital and will require urgent surgical repair.

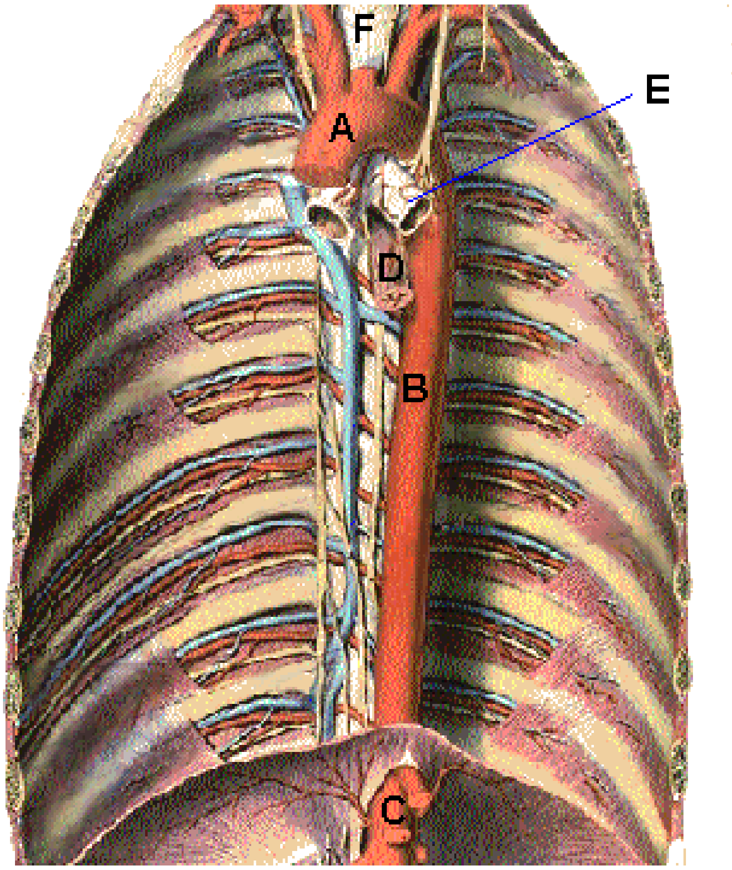


Figure 21: The aorta (A,B,C)

(reproduced from Dr Schueler's CD ROM)

The aorta lies adjacent to the spinal column on the posterior chest wall. The intercostal vessels lie just under each rib and are vulnerable to relatively superficial stabbing attempts.

Liver laceration

The position of this large solid organ varies with the movements of breathing. It can be reached by a knife entering the victim through the lower chest and upper abdomen particularly from the front and right side. Bleeding from a liver laceration may be torrential and fatal without timely surgical intervention.

The ISS for this injury depends on the depth of liver penetration.

Splenic laceration

The spleen is a vascular organ and has a relatively fixed position, lying just under the 9^{th} and 10^{th} ribs on the left side of the chest wall. A penetrating injury to the spleen may also cause torrential bleeding and because of its proximity to the pleura, may be associated with a pneumothorax and diaphragmatic injury.

The ISS for a splenic laceration is 9. The ISS for a splenic laceration with an associated pneumothorax is 18.

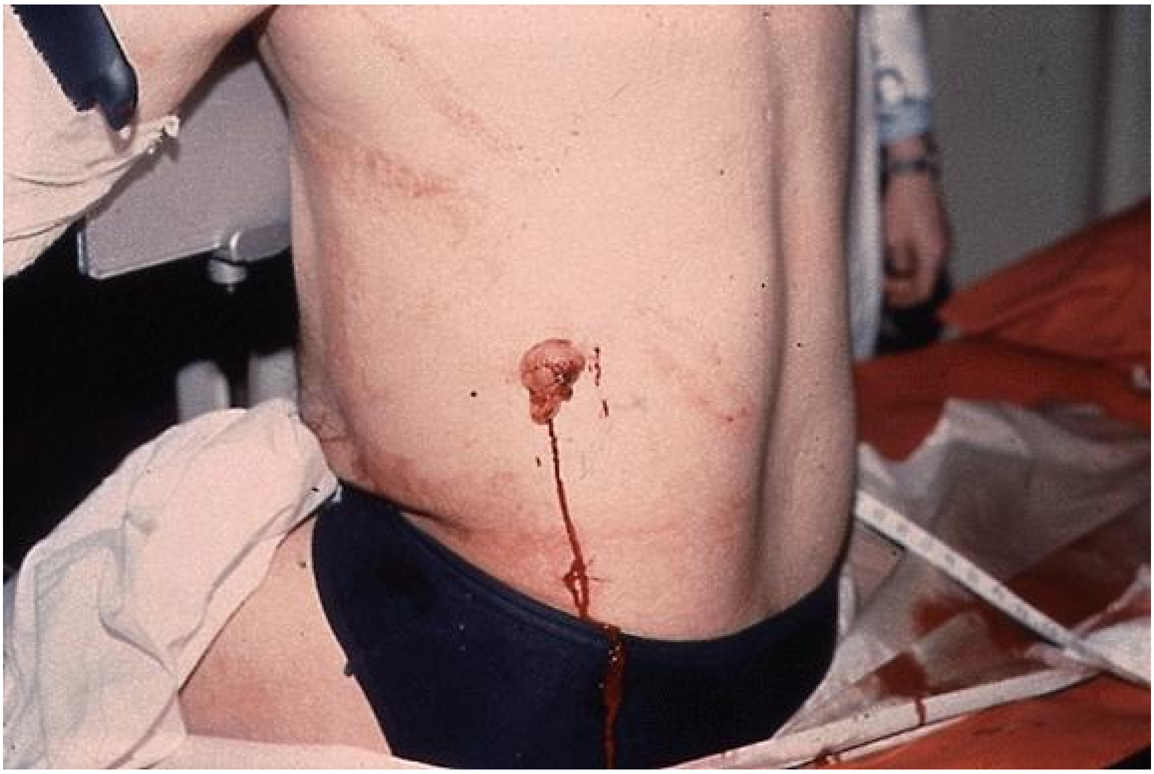


Figure 22: Extrusion of viscera through a stab wound in the left flank

Cardiac lacerations

More than half of patients stabbed in the heart will die [47,48]. Those that reach hospital alive will require urgent open chest surgery. Most stab wounds to the heart breach the right ventricle [46].

Pericardial tamponade - a penetrating wound to the heart may allow blood to accumulate in the fibrous pericardium which encloses and surrounds the heart. This blood may not be able to escape, and with each spurt of blood from the lacerated heart its volume increases. Eventually the growing volume of blood in the pericardial space will compress the heart and prevent it from filling. This condition is usually rapidly fatal unless promptly recognised and treated surgically.

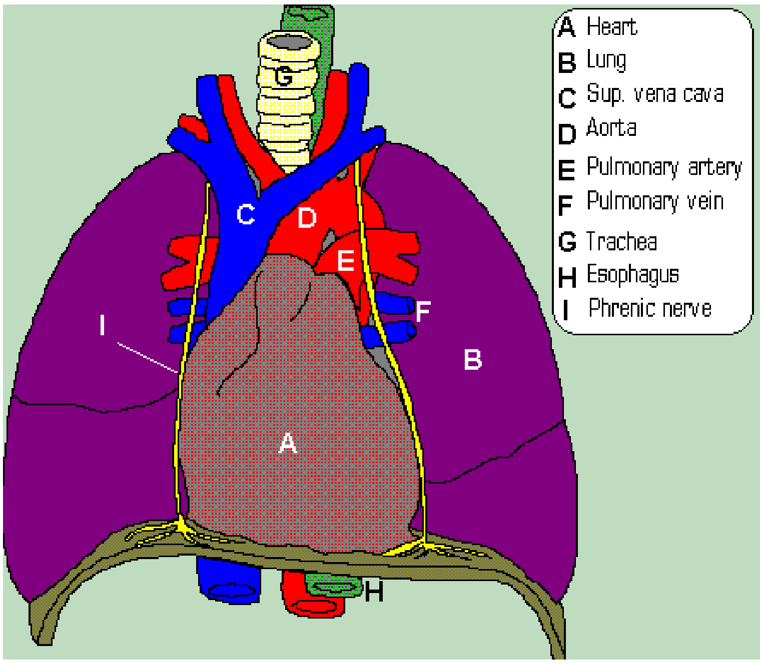


Figure 23: The internal thoracic organs

(reproduced from Dr Schueler's CD ROM)

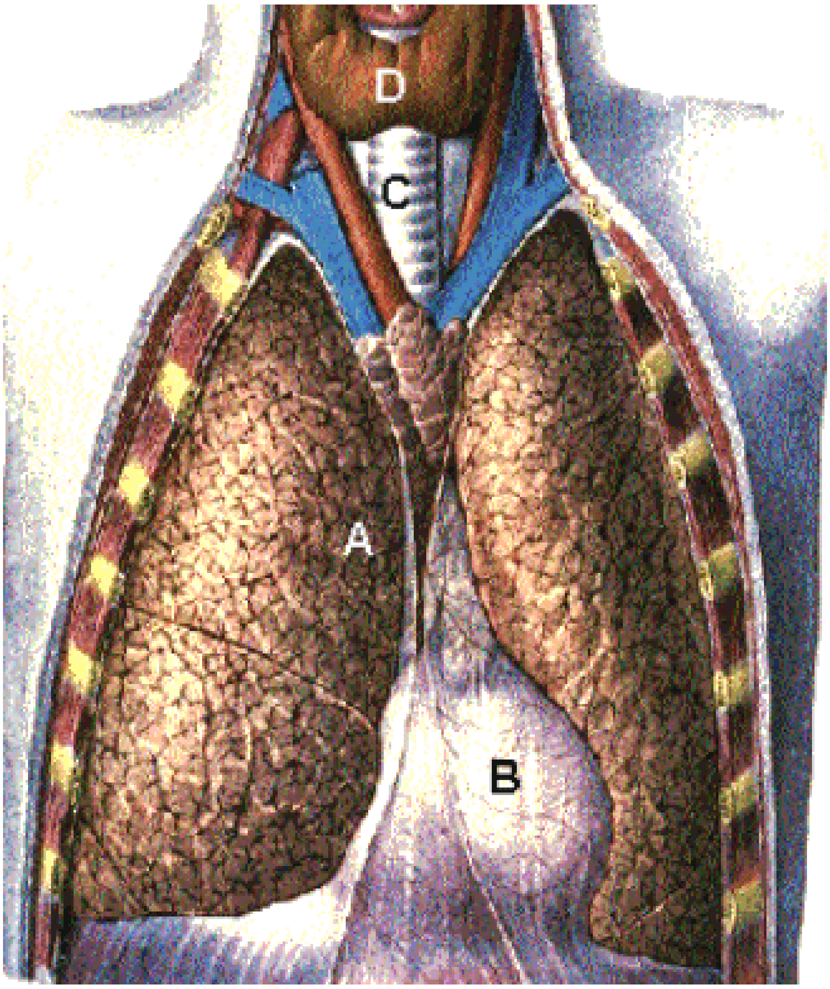


Figure 24: The heart and lungs

(reproduced from Dr Schueler's CD ROM)

the heart is enclosed by the pericardium (B)

Kidney

Stab wounds to the lower and middle back can involve the kidneys, although they are situated quite deeply. The kidney can bleed profusely as they receive approximately 25% of the cardiac output.

The ISS for a lacerated kidney is 16.

Bowel injury

A perforated bowel is unlikely to cause death by major haemorrhage, however the leakage of bowel contents into the abdominal cavity is likely to cause contamination and peritonitis, and may require surgery.

The ISS for this injury is 9.

Stomach

The stomach is a large hollow organ, the size and position of which will vary greatly with its degree of distension after eating. There will also be movement with breathing. The consequences of perforation are similar to those described for the bowel.

The ISS for this injury is 9.

Mesentery

The bowel is suspended by this large structure which supplies it with its blood and lymphatic supply. Mesenteric lacerations can cause significant haemorrhage.

The ISS for a mesenteric laceration is 9.

Oesophagus

This organ descends in proximity to the spine and is relatively inaccessible to a knife attack. The consequences of a stab wound to this structure can be catastrophic due to contamination of the chest cavity in which it lies (the mediastinum).

The ISS for a lacerated oesophagus is 16.

Major blood vessels and nerve groups

In addition to the injuries described above, catastrophic haemorrhage may result from stab wounds to the neck (carotid and jugular vessels); the groin (femoral vessels); the axilla (under the arms) and the subclavian vessels (behind the collar bone).

Body armour for police use is unlikely to be able to protect these vessels without unduly restricting the wearer's ability to move comfortably.

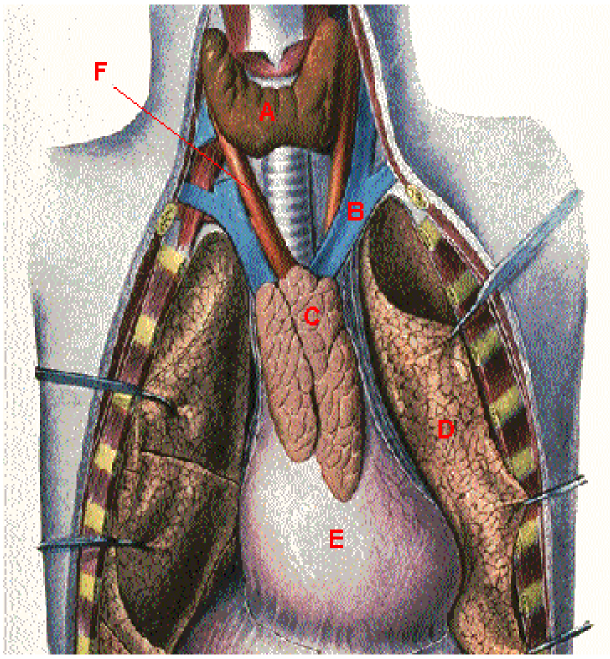


Figure 25: The brachiocephalic vein (B)

(reproduced from Dr Schueler's CD ROM)

The brachiocephalic vein leads into the subclavian vein which is vulnerable to a downward stabbing attack

The major blood vessel groups described here are in close proximity to major nerve groups. These are therefore vulnerable to injury when these blood vessels are involved in penetrating trauma.

Within the abdomen and lower chest there are other major blood vessels which may bleed torrentially when breached by a penetrating knife wound. Among these is the inferior vena cava which carries the venous blood from the lower half of the body to the heart.

A lacerated inferior vena cava has an ISS of 16.

Spinal cord injury

The spinal cord is protected inside the bony vertebral canal and is unlikely to be harmed in a random stab wound.

Other organs

Other organs are at risk of injury in knife attacks. These include the pancreas, bladder, gall bladder, reproductive organs and the adrenal glands. These injuries are not commonly seen in clinical practise.

Multiple organ injuries can be caused by a single stab wound. Clearly, as the number of stab wounds increases so does the potential for multiple organ injuries. When this occurs, the AIS scores need to be summated in the NISS system.

Injuries from Arrested Ballistic Trauma

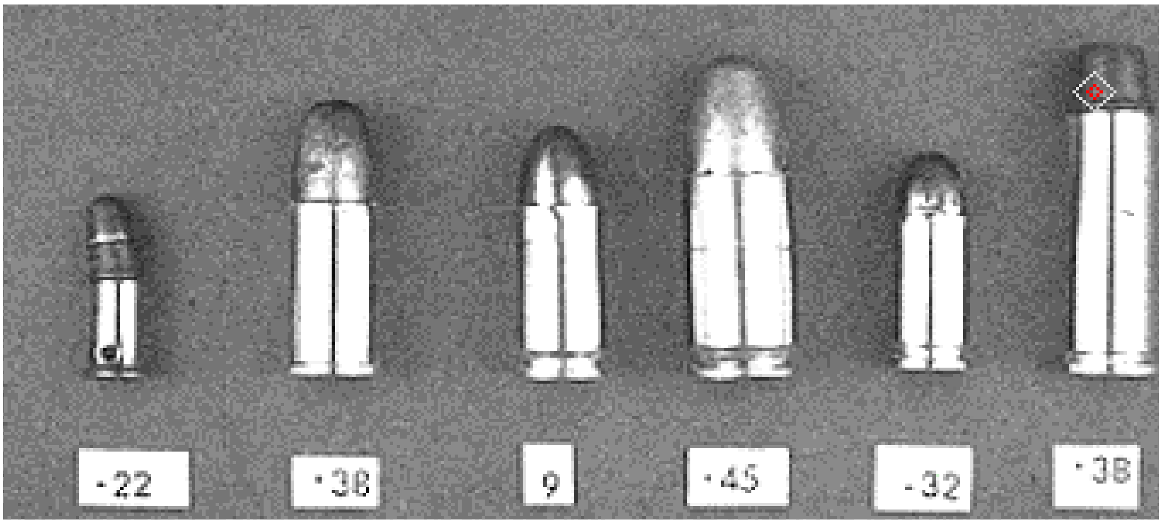


Figure 26: Common handgun ammunition

When an individual is hit by a bullet, the injuries sustained depend upon where the bullet strikes the body, the trajectory of the missile, and the cavitation caused by the passage of the shock wave [49]. The primary purpose of armour is to prevent penetration into the body. As the projectile is slowed and stopped by body armour, a crater is produced resulting in backface deformity. The injury potential from backface deformity is low. There have been reports of injury from this phenomenon, but we have learned from the American experience that serious injury and death are rare in arrested ballistic strikes when the armour has stopped a bullet that it was designed to stop. The evidence from America is overwhelming; survivors of arrested ballistic strikes by far outnumber fatalities [4].

It is also clear from recent experience in American Emergency Medicine centres that body armour saves lives in shootings [50]. Soft body armour is capable of stopping penetration by the low energy missiles of most handguns. The kinetic energy of the missile must still be dissipated and expended in the deformation of the missile, the armour, and the underlying tissues of the body.

This has resulted in armour-protected gunshot victims attending emergency departments with relatively innocuous appearing, non-penetrating injuries. Although missile penetration is prevented, there are some reports of underlying organ injury in these individuals. Currently, it is recommended that all victims of non penetrating ballistic injury be observed closely in hospital, despite apparent good health and innocuous skin lesions [50].

Arrested ballistic injury to the trunk may cause pulmonary contusion - a bruise to the lung. This was the most common injury sustained by animals in ballistic tests with soft body armour, and likely to be the most common injury in human victims of arrested ballistic injury. The shock wave causes small zones of bleeding and disruption of the lung tissue as it crosses the interface between lung tissue and air [29,32].

Soft tissue contusions are likely to occur and have been reported in saved body armour wearers. Presumably, there is also a risk of rib fractures. These are unlikely to be life threatening [50].

Body Coverage

The ideal body armour would protect the whole body from injury by any weapon. With current technology, a garment providing this protection would be unwearable. The best compromise between protection and wearability remains to be found.

The risk of death following injury to the internal organs has been described. This is explored in more detail in the retrospective study of 500 victims of penetrating trauma and is presented later. With this information, it is possible to map the body into high, medium and low risk areas. It is then relatively straightforward to protect these areas of the body with armour of appropriate and corresponding protective properties. This will become evident later in this thesis.

PART 7: AN ASSESSMENT OF THE VULNERABILITY OF REGIONS OF THE HUMAN BODY TOWARDS STAB ATTACKS

Introduction

Manufacturers produce body armour in widely varying shapes, designs and areas of body coverage. Attempts have been made to reduce areas of coverage so as to reduce weight and improve wearability. At present, there are no agreed guidelines for body coverage.

This study seeks to identify the areas of the body most at risk from stabbing attacks in both qualitative and quantitative terms so that body armour can be designed to protect the most vulnerable areas, while not restricting movement in less vulnerable areas.

Methods

A computerised, retrospective search was carried out on 500 consecutive patients attending the Accident and Emergency department of Glasgow Royal Infirmary between 1993 and 1996 following penetrating trauma. Patients were identified from their discharge diagnosis. STAG (Scottish Trauma Audit Group) records for penetrating trauma victims were identified for the same period (STAG collates information on patients with major injuries who died, or who were in-patients for more than 72 hours).

Each patient record was studied and the location of all penetrating injuries for each patient was marked on one of four anatomical figures (Figures 27 - 30 below).

Each wound was colour-coded according to severity, these are defined here:

- **minor** - not a threat to life or limb, these were given an average AIS score of 1.
- **major** - wounds that resulted in major blood loss, threat to life, tendon damage, bone involvement, major neurovascular injury or permanent major cosmetic deformity, these were given an average AIS score of 3.
- **devastating** - fatal or near-fatal (patients in the near-fatal category arrived at hospital in cardiac arrest or in a moribund state), these were assigned an average AIS score of 5.

The total number of wounds in all three categories of severity were plotted on the anatomical figures and are presented.

Figures 27 – 30 are copies of the anatomical charts used to plot the site of the wounds. These charts were designed so that the lines of demarcation correspond to prominent bony landmarks and other clear surface anatomical features. These are described here.

The location of wounds was determined exclusively by clinical notes and sketches.

Anatomical Demarcation Lines

On the anterior sketch (Figure 27), a vertical line passing through the lateral angle of the eye divides the anterior and lateral aspects of the face. The clavicle marks the lower border of the neck and the upper limit of the anterior chest. The shoulder region corresponds to the margins of the deltoid muscle. The divide between the upper and lower halves of the chest is marked by a line running through the nipples at the level of the fourth intercostal space, this line continues around the back.

The divide between the lower chest and upper abdomen is defined by the lower costal margin. The level of the umbilicus divides the upper and lower halves of the abdomen. The femoral (groin) upper border lies over the inguinal ligament and extends three inches inferiorly onto the front of the thigh. The upper and lower borders of the knee have been defined from the upper border of the femoral condyles to level of the tibial tuberosity.

On the lateral sketches (Figures 28 and 29), the loin is represented by the area posterior to the anterior axillary line. The axilla has not been included as no wounds were inflicted to this area. The lateral aspects of the arms correspond to the ulnar aspect typically associated with the defensive surface of the forearm.

On the posterior sketch (Figure 30), the lower border of the neck crosses the spinous process of C7. The lumbar spine commences at L1. The upper border of the buttocks commences at the level of the top of the bony pelvis.

Figure 27: Anterior view with anatomical regions

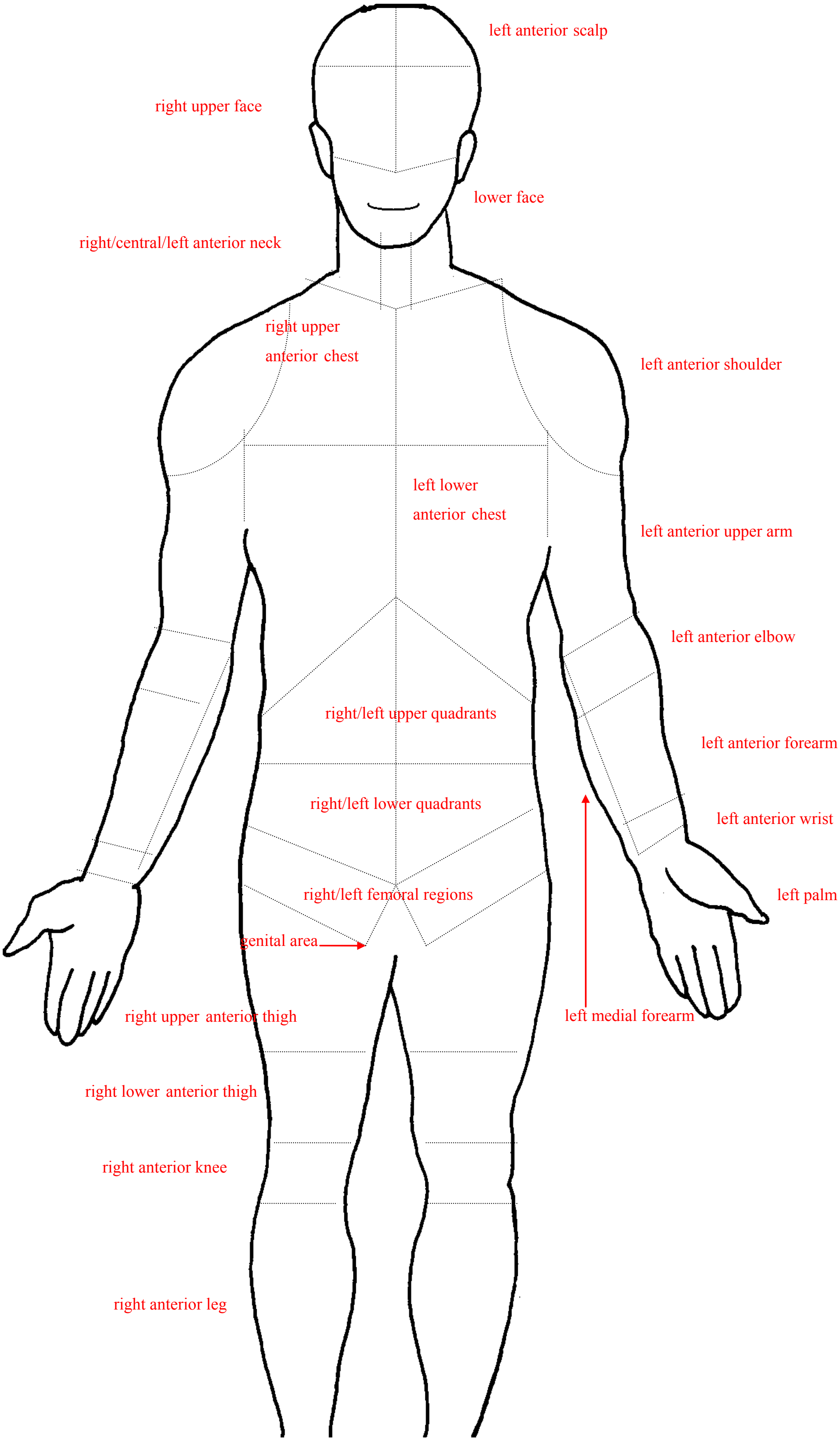


Figure 28: Right lateral view with anatomical regions

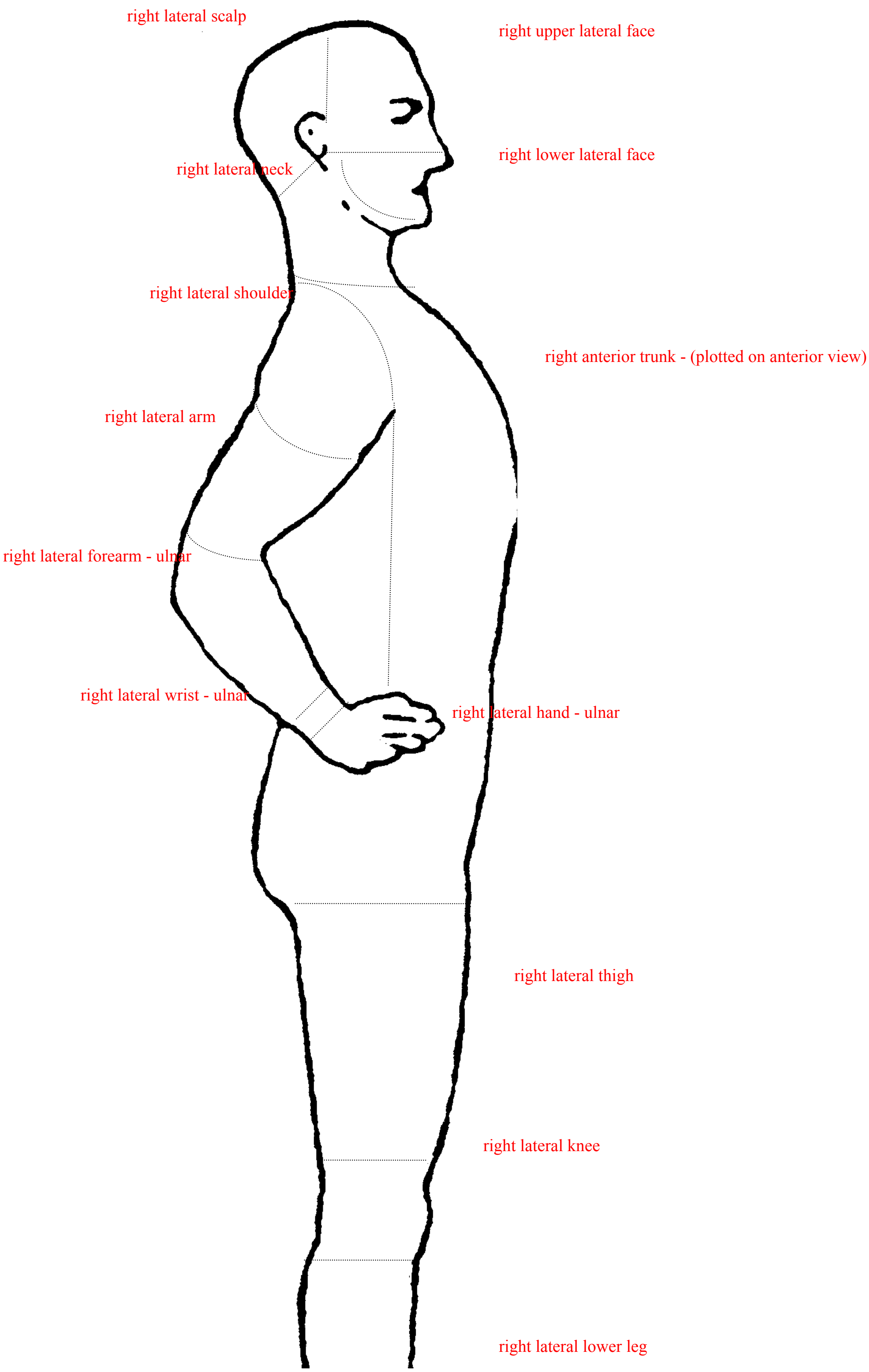


Figure 29: Left lateral view with anatomical regions

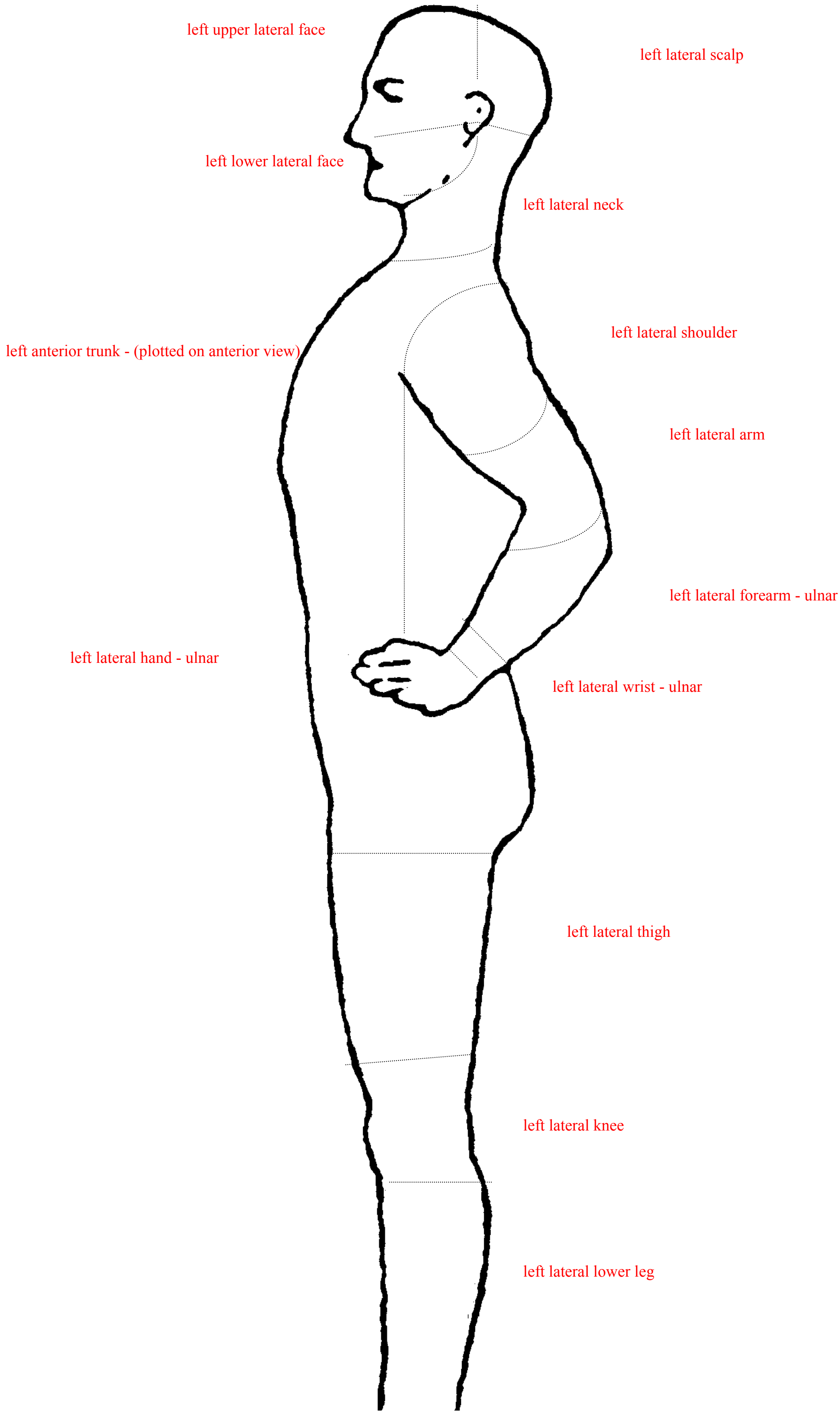
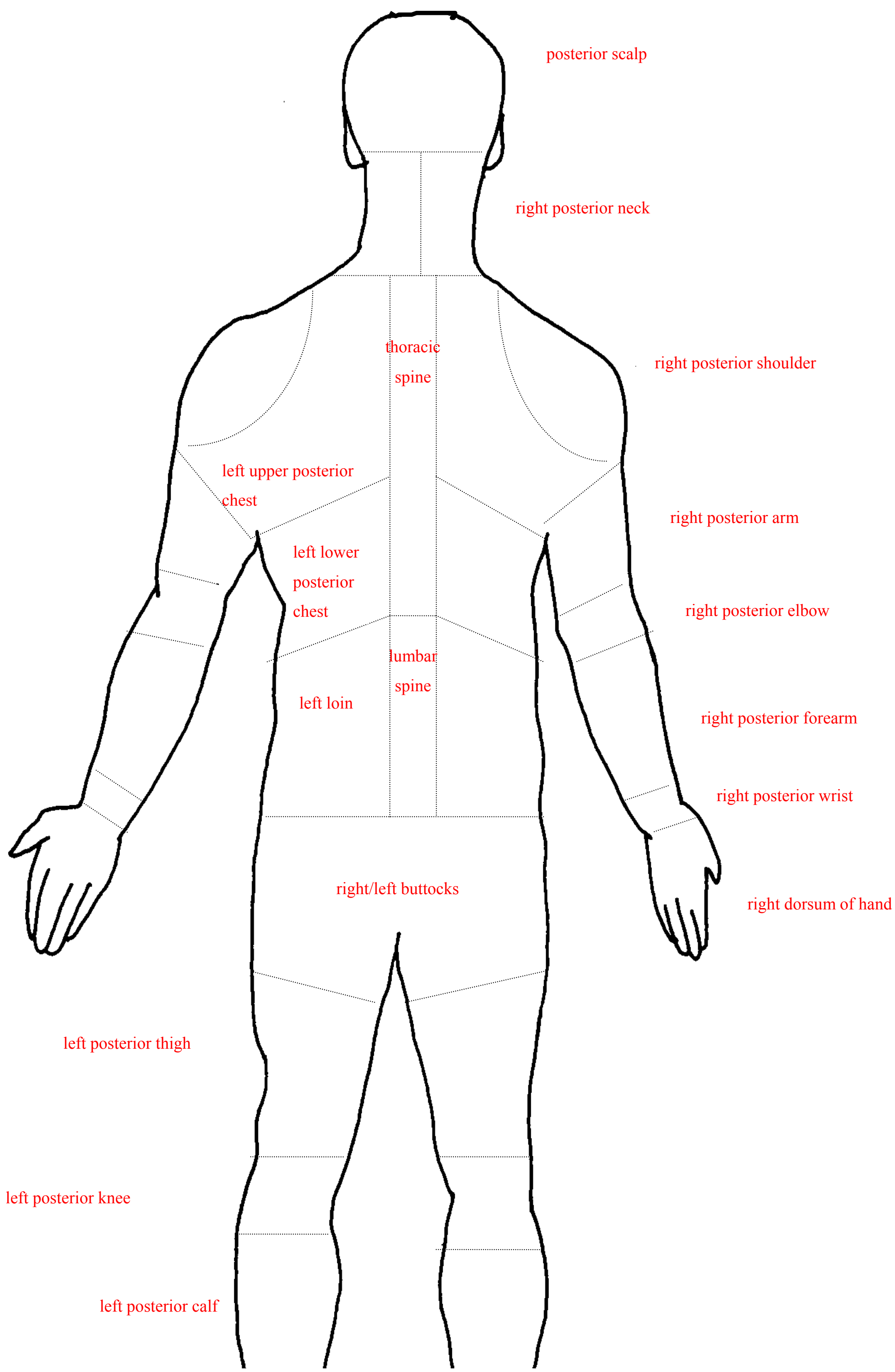


Figure 30: Posterior view with anatomical regions



Results

Of the 500 records of victims of penetrating trauma, 51 were excluded from this study as they were incomplete, or because the wounds were self-inflicted or not caused by assault. Of the remaining 449, 18 were identified as gun shot injuries.

431 of the 500 patients had been stabbed. Of these, 405 were male and 26 female.

Figures 31 - 34 show the anatomical distribution of the total number of minor wounds. Each minor wound has been assigned an AIS of 1. These wounds did not result in limb or life-threatening injuries, but will have caused minor permanent cosmetic deformity and some will have caused significant blood loss.

Figures 35 - 38 show the anatomical distribution of the major wounds, (each allocated an AIS of 3). These resulted in major blood loss, tendon damage, bone involvement, major neurovascular injury or major permanent cosmetic deformity.

Figures 39 - 42 show the anatomical distribution of the ‘devastating injuries’ (fatal or near-fatal), each was assigned an AIS of 5.

Figure 31: Minor wounds - anterior

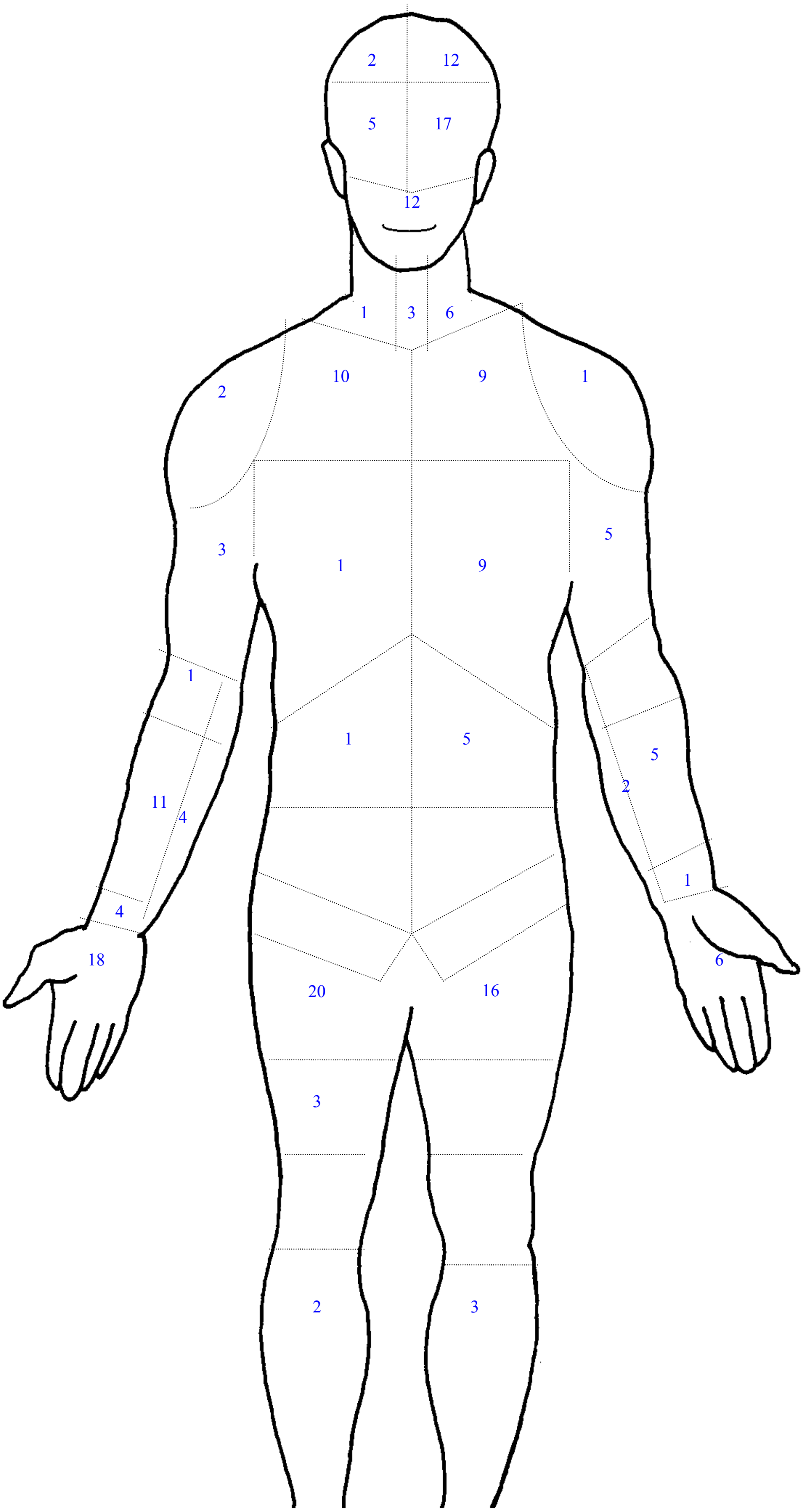


Figure 32: Minor wounds - right side

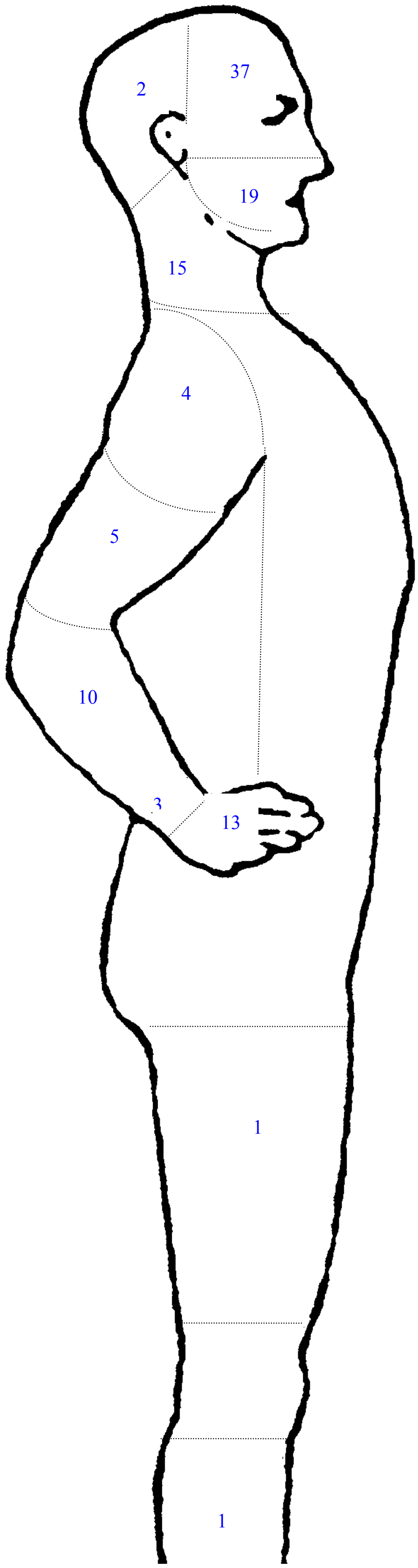


Figure 33: Minor wounds - left side

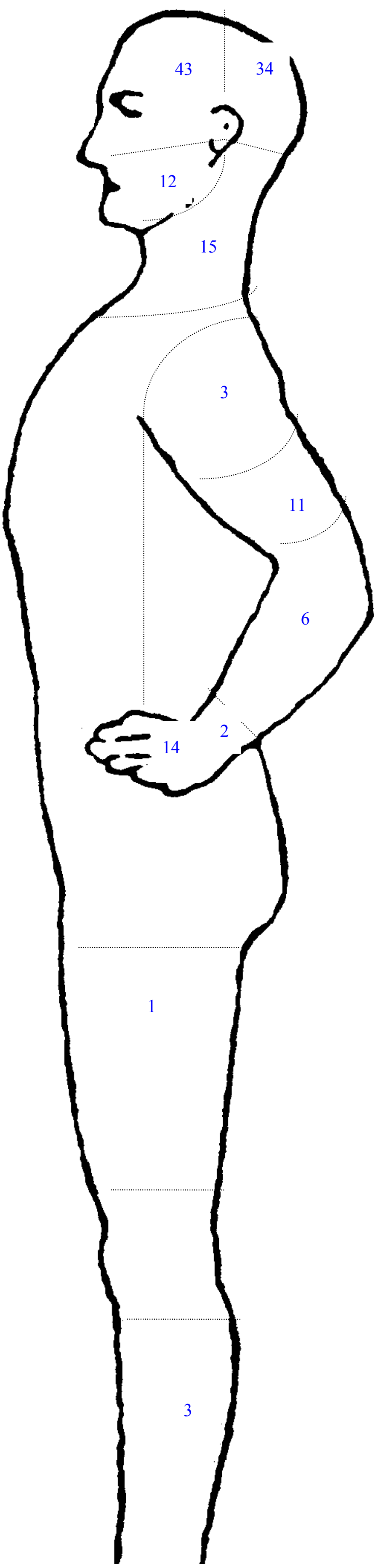


Figure 34: Minor wounds - posterior

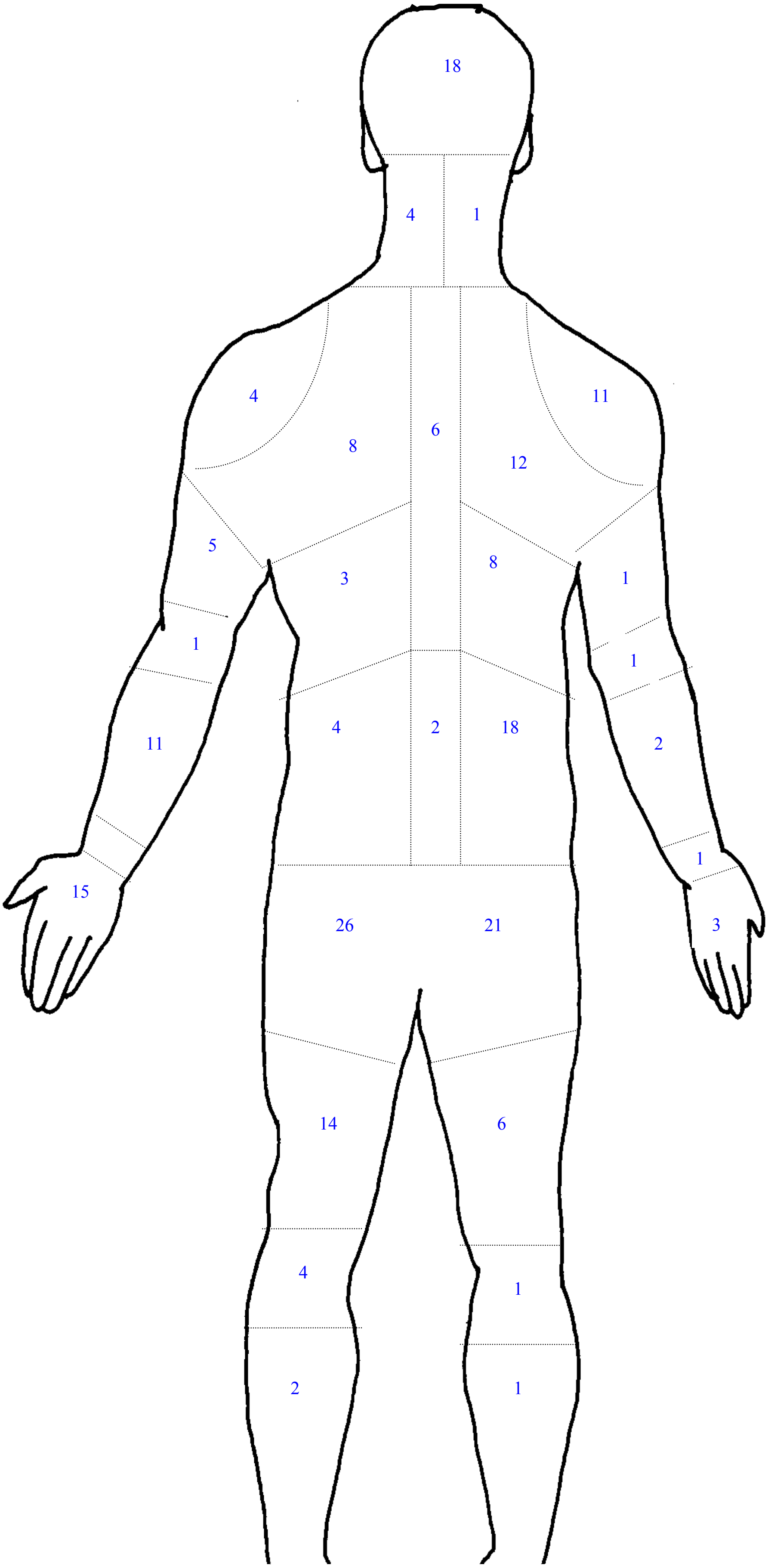


Figure 35: Major wounds - anterior

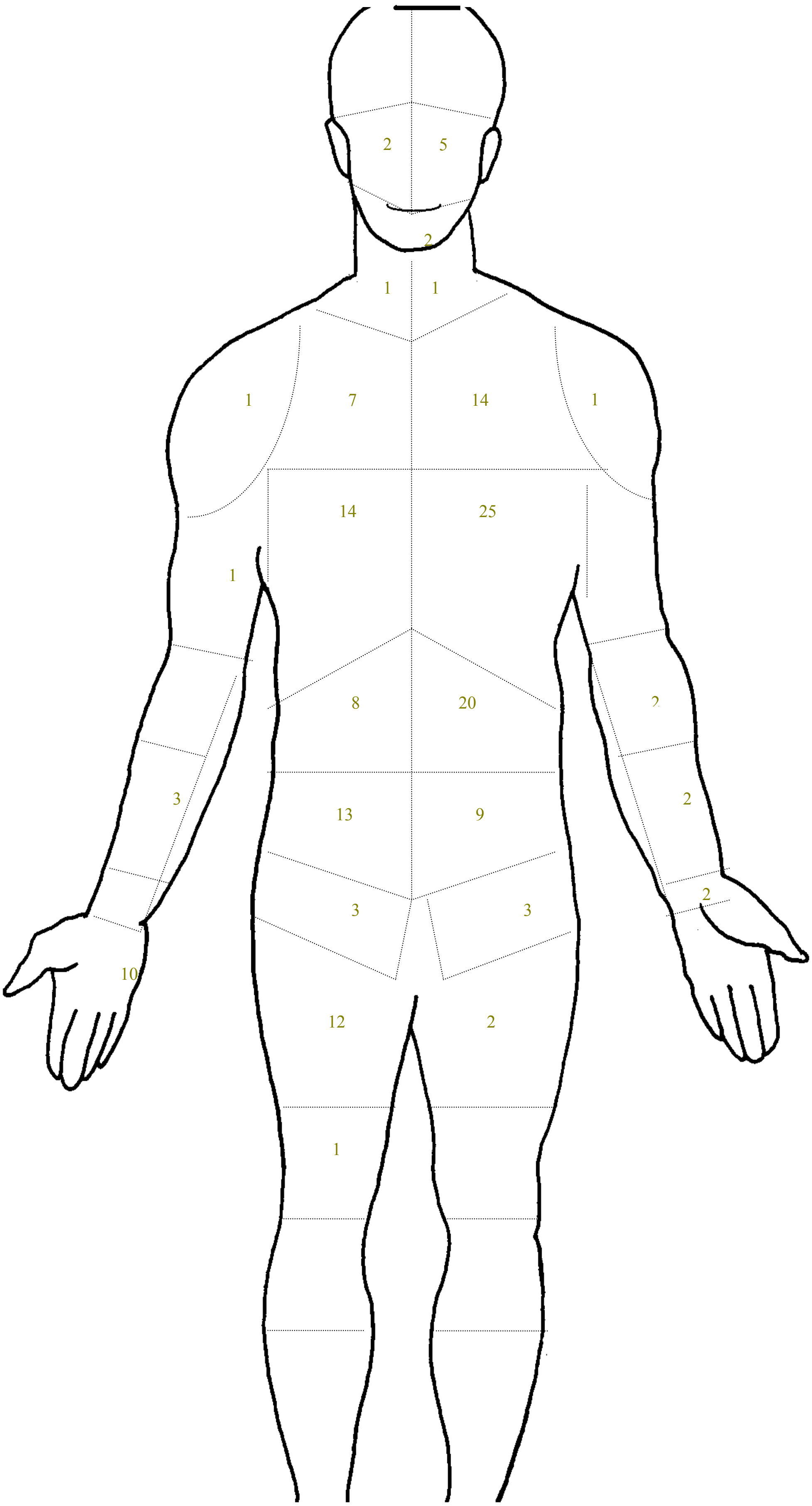


Figure 36: Major wounds - right side

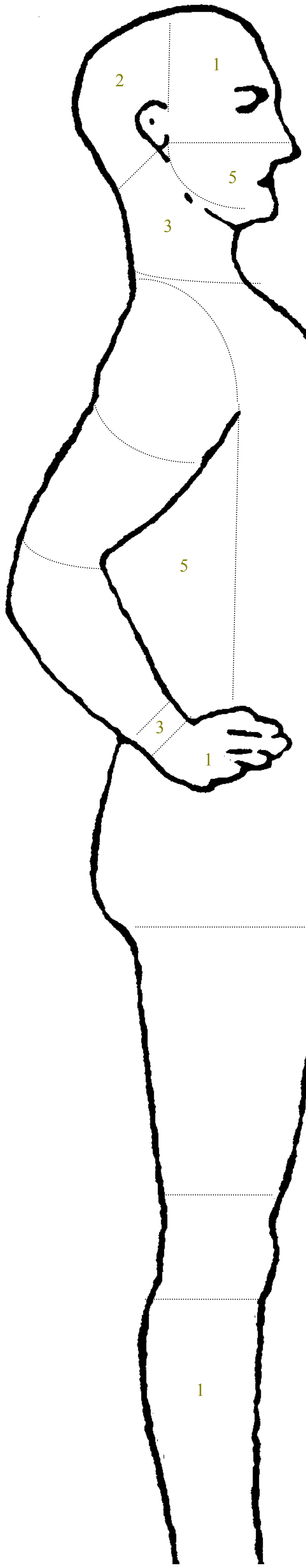


Figure 37: Major wounds - left side

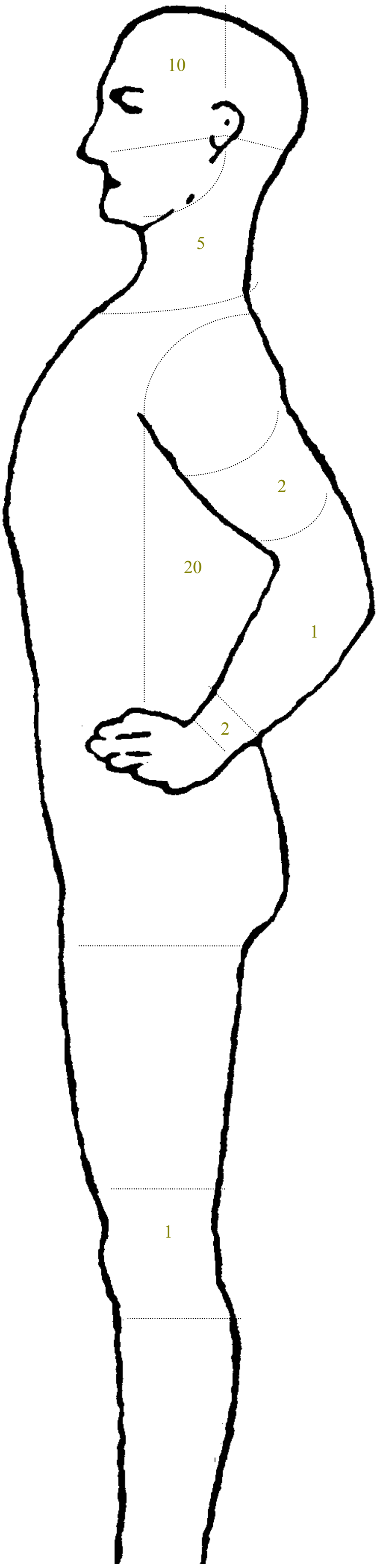


Figure 38: Major wounds - posterior

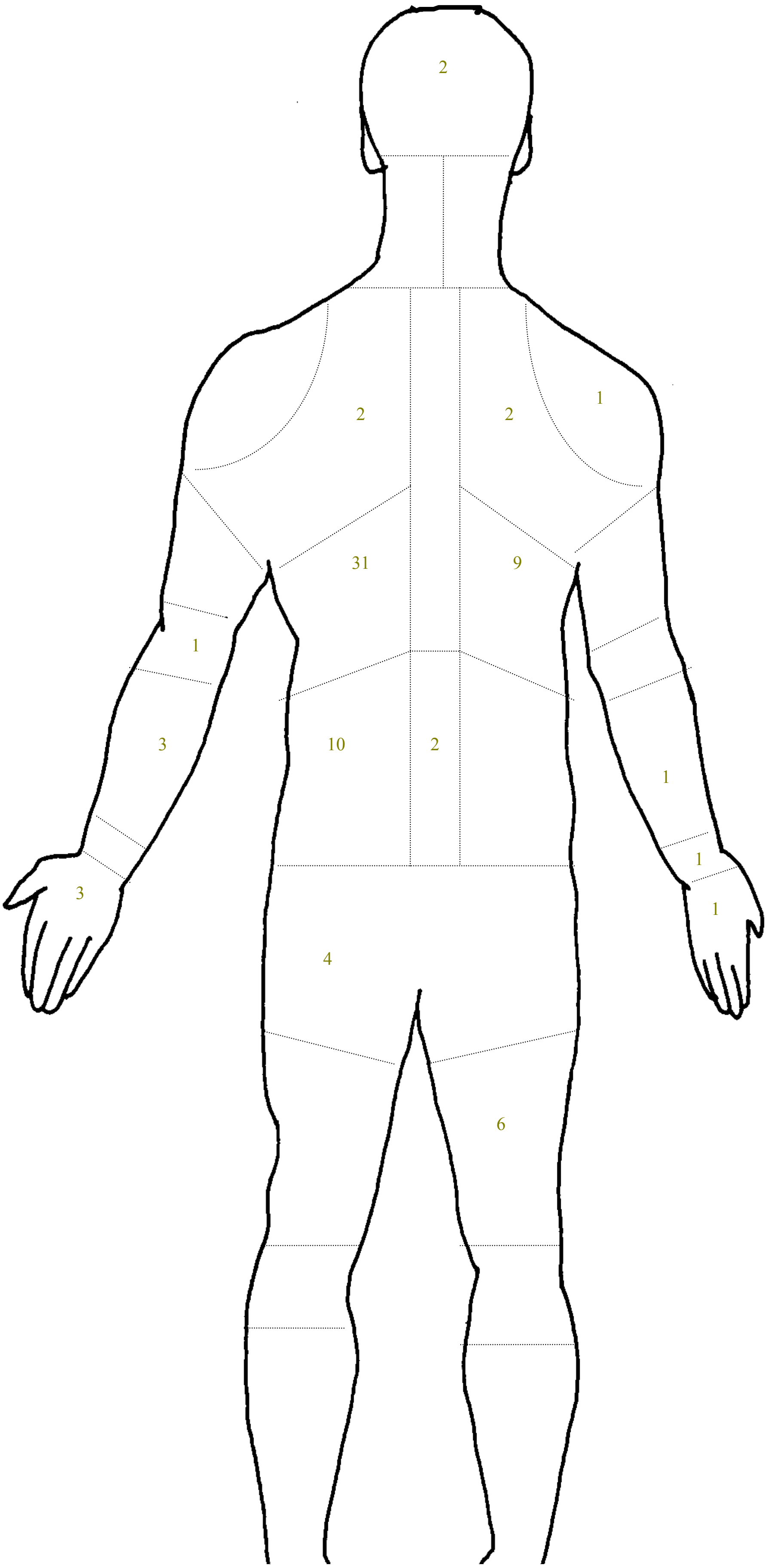


Figure 39: Devastating wounds - anterior

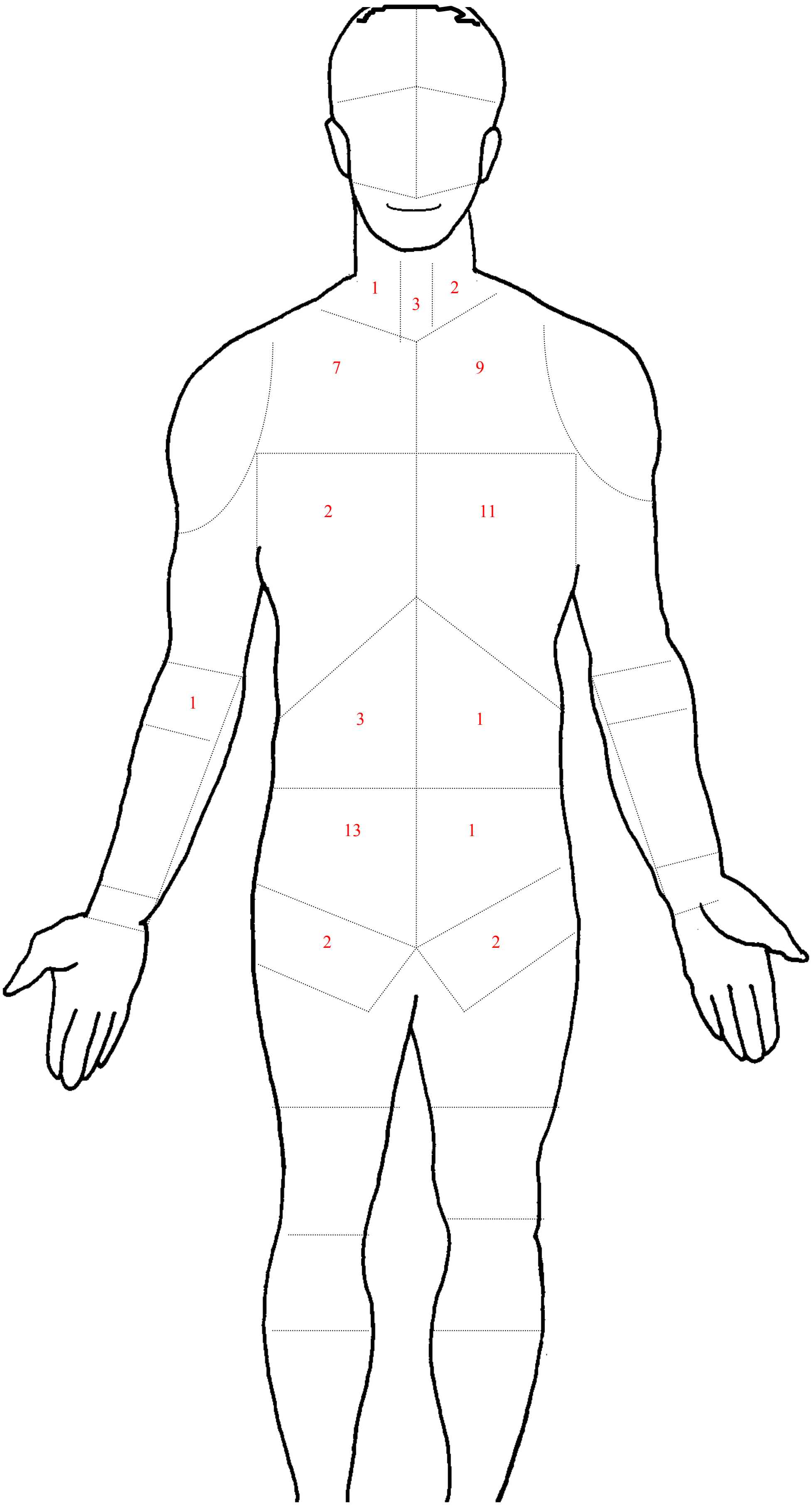


Figure 40: Devastating wounds - right side

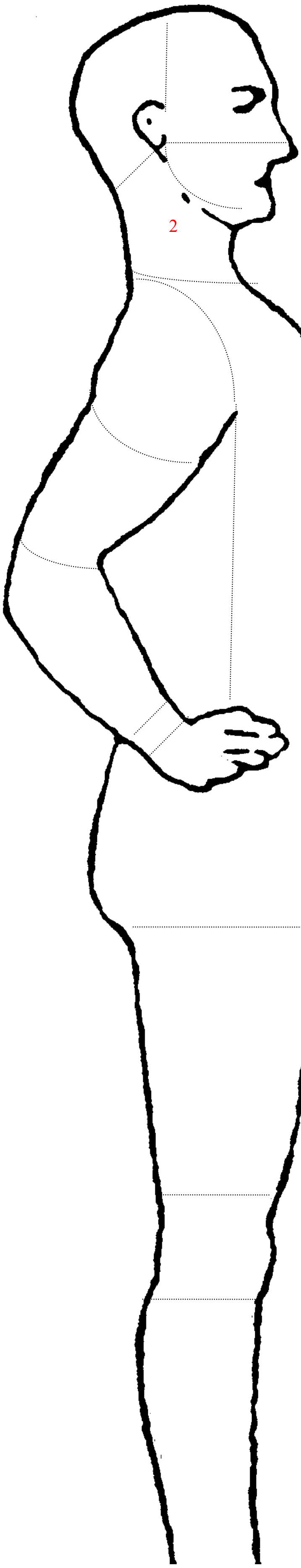


Figure 41: Devastating wounds - left side

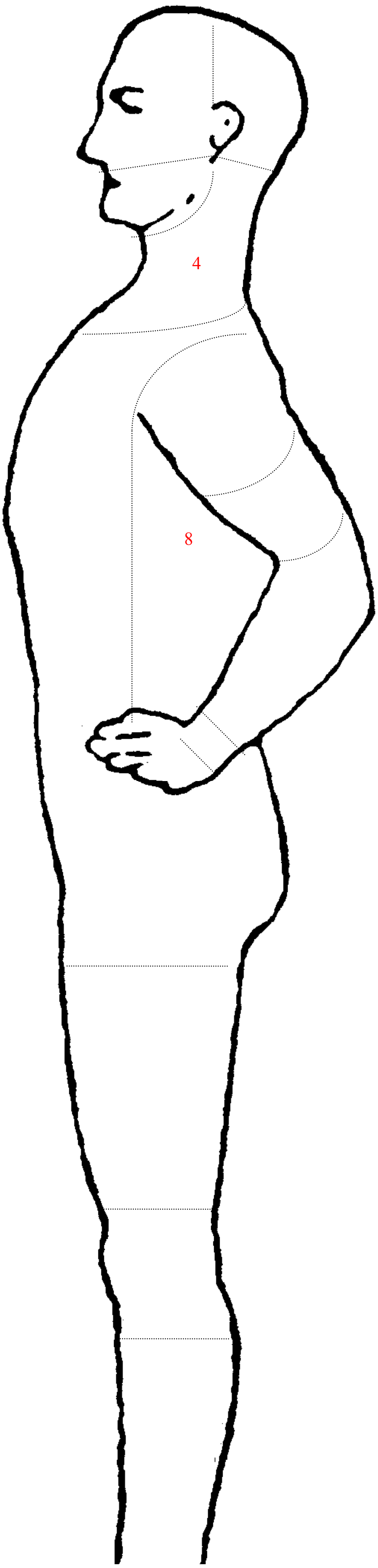
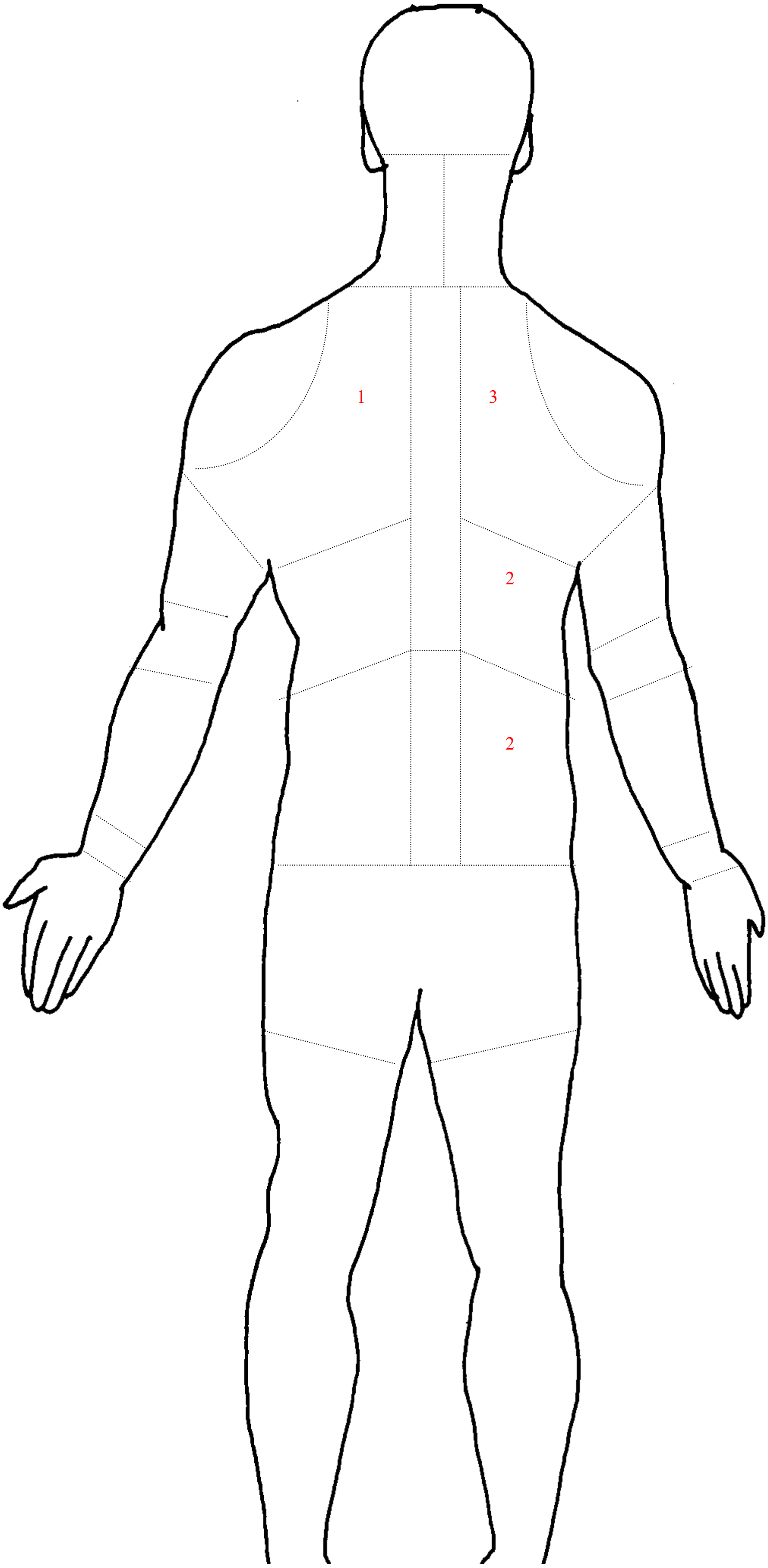


Figure 42: Devastating wounds - posterior



Severity of stab wounds

The distribution of wounds for stabbing attacks by severity is presented.

Table 11: Severity of wounds

Severity of wound	Number	% of all wounds
Minor (AIS 1)	656	63.3
Major (AIS 3)	301	29
Devastating (AIS 5)	80	7.7
TOTAL	**1037**	**100**

To simplify presentation, I have amalgamated some of the smaller areas of the anatomical sketches for the tables presented here.

Table 12: Distribution of wounds by region and severity

Region	Minor wounds	Major wounds	Devastating wounds	Total wounds
head (face and scalp)	203	29	0	232
neck	45	10	12	67
shoulders	25	3	0	28
left chest	29	92	29	150
right chest	31	37	14	82
right abdomen	27	21	18	66
left abdomen	21	39	2	62
right groin	0	3	2	5
left groin	0	3	2	5
thighs	61	21	0	82
buttocks	47	4	0	51
right arm	80	21	1	102
left arm	87	18	0	105
TOTAL	656	301	80	1037

To demonstrate the probability of sustaining a wound of a given severity in a particular anatomical location in a stabbing assault, the table above is presented in percentages.

Table 13: Distribution of wounds by region and severity in percent

Region	% of all minor wounds	% of all major wounds	% of all devastating wounds	% of all wounds
head (face and scalp)	31	9.6	0	22.3
neck	6.9	3.3	15	6.5
shoulders	3.8	1	0	2.7
left chest	4.4	30.5	36.2	14.4
right chest	4.7	12.3	17.5	7.9
right abdomen	4.1	6.9	22.5	6.4
left abdomen	3.2	12.9	2.5	6
right groin	0	1	2.5	0.5
left groin	0	1	2.5	0.5
thighs	9.3	6.9	0	7.9
buttocks	7.1	1.3	0	4.9
right arm	12.2	6.9	1.2	9.8
left arm	13.2	5.9	0	10.1

Regional Scoring

To render these figures applicable to body armour design, it is useful to plot the relative risk for each anatomical region in a stabbing assault. In doing so I present the original anatomical figures with regional scoring.

To determine the regional score, and hence the regional risk to injury in edged weapon assault, the AIS scores for all wounds in each anatomical region are summated. This number is then divided by the number of wounds in the region. This calculation produces the regional wound score.

These are plotted on the anatomical diagrams in Figures 43 - 46.

Figure 43: Regional wound scores - anterior

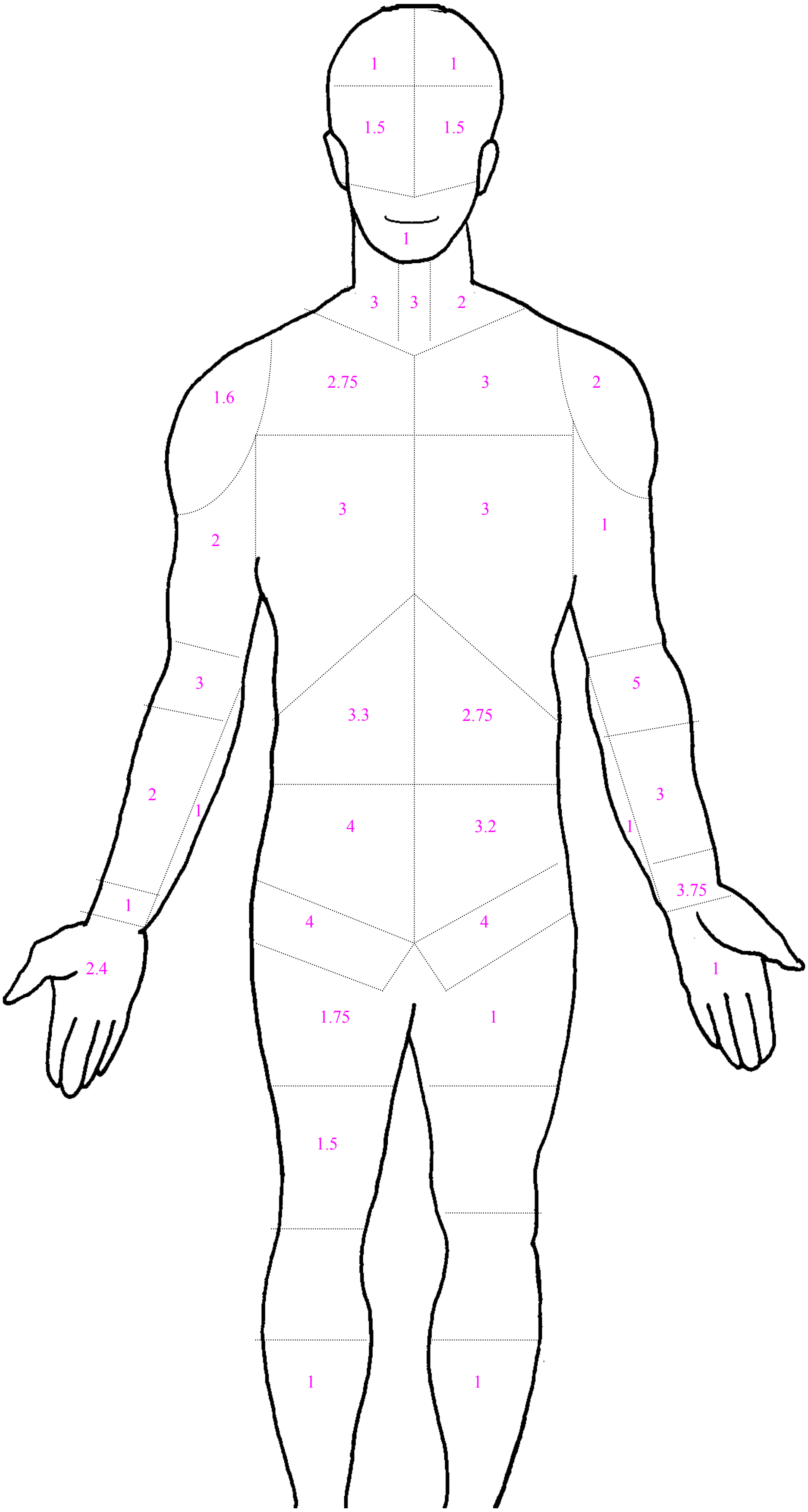


Figure 44: Regional wound scores - right side

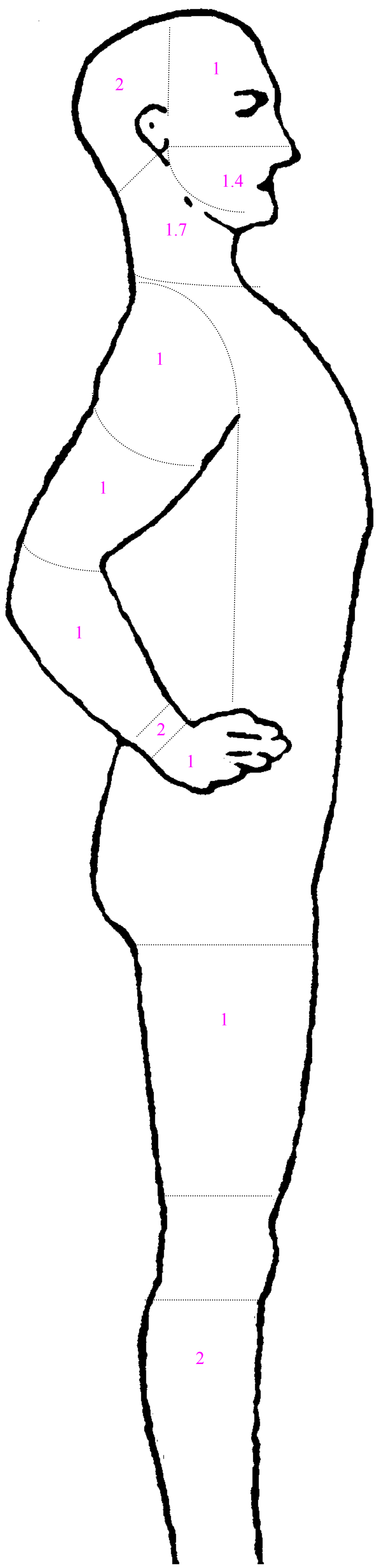


Figure 45: Regional wound scores - left side

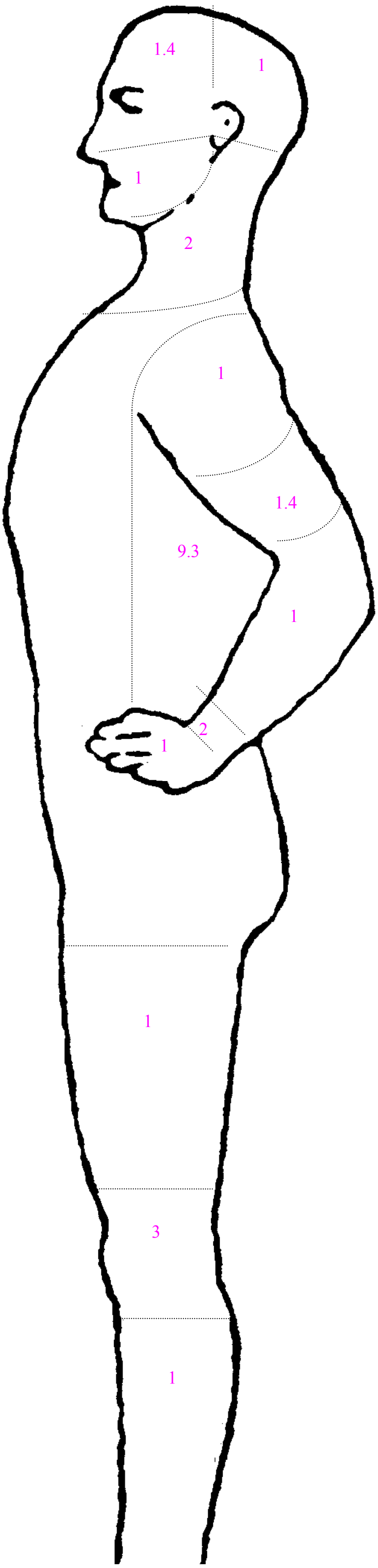
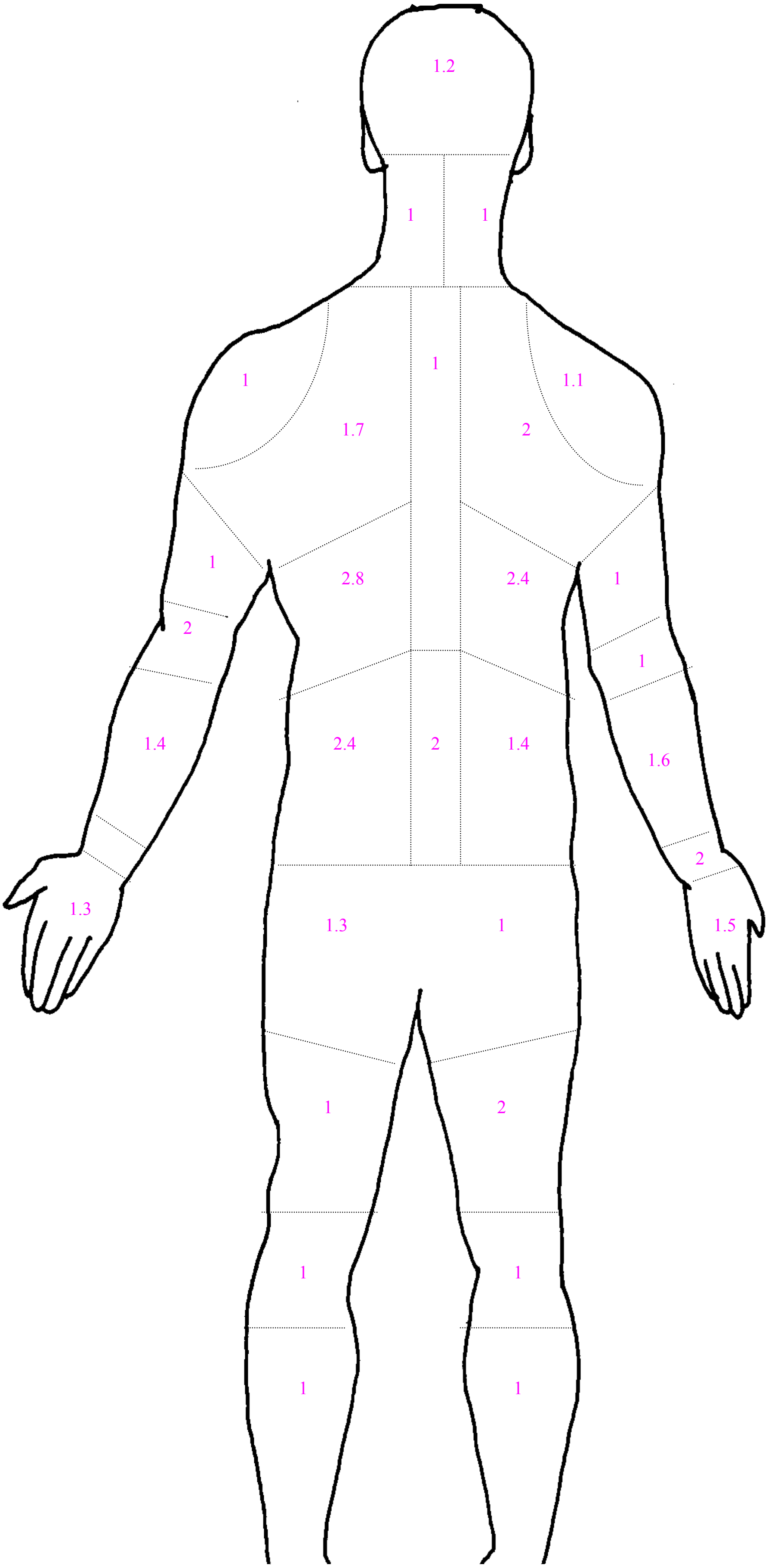


Figure 46: Regional wound scores - posterior



Having established this regional risk map of the body, it is now possible to consider designing a body armour garment that will provide maximal anti-stab protection to the high risk areas, moderate protection to the areas at moderate risk, and lower protection to the lower risk areas. This concept will be explored in a later section.

This study has identified the areas of the body most at risk. It remains to determine how much knife penetration can be permitted through body armour in each region of the body. This will become evident in the CT study presented in the next section.

Other Observations from this Study

The distribution of wounds, particularly the major and devastating wounds, would confirm that the majority of assailants are confrontational and right handed. The surprisingly high incidence of serious injury to the left loin perhaps is influenced by the defensive stance of the victim who has presented the non-dominant side of the body towards the assailant.

A significant number of injuries occurred on the ulnar (defensive) aspect of both forearms. This is an area presented to an assailant in defence. It might therefore be reasonable to consider incorporating anti-slash material into the ulnar aspect of the sleeves on police uniforms.

Wounding to the neck cannot feasibly be prevented by ergonomically acceptable body armour. Defence training, including the use of batons and incapacitant sprays, is the only realistic way of addressing this problem.

Similarly, body armour cannot protect the face and scalp. Knife wounds to these areas need to be addressed by using protective helmets and improving defence training.

PART 8: SAFETY STANDARDS FOR STAB-RESISTANT BODY ARMOUR:

A COMPUTER TOMOGRAPHIC ASSESSMENT OF ORGAN TO SKIN DISTANCES

Introduction

The risk of serious wounding and death by anatomical region has been presented. To further understand the risks of wounding and the need for regional protection by body armour, we need to determine the accessibility, and hence the vulnerability of the internal organs to a knife blade.

The anti-stab protection offered by body armour is quantified by the distance a test blade penetrates through beyond a test sample at a given energy. This implies that organs will remain undamaged if they are protected to this depth by overlying soft tissue.

Two standards are currently proposed for test blades delivering 42 Joules of energy: 20mm of penetration (National Institute of Justice, USA) [24] and 5mm (Police Scientific Development Branch, Home Office) [25]. Increasing the protective properties of body armour increases the weight and bulk of the garment and reduces a police officer's ability to perform his duties. 42 Joules is considered to be representative of the "average" stab attempt [25].

Axial Computer Tomography (CT) scanning provides data on the distances of organs from the skin. The purpose of this study is to determine which organs would be vulnerable to penetrating injury commonly involved in stabbing injuries to the trunk for each of the proposed body armour knife resistance standards.

Methods

A retrospective study was performed on consecutive torso CT scans at two general hospitals. 71 thoracic and abdominal scans on patients aged between 20 and 40 were reviewed (this age range was felt to be representative of the majority of serving police officers).

Two radiological colleagues (Dr M.J. Duddy of University Hospital Birmingham, and Dr S.E.J. Connor of Birmingham Heartlands Hospital) measured the minimum skin to organ distances on a CT console.

Skin to organ distances were measured for visceral pericardium, pleura, thoracic aorta, liver, spleen, kidneys, abdominal aorta and femoral artery. A visual survey was performed of each structure on the CT console, reviewing all relevant slices. The three shortest distances from the skin and, through soft tissues, to each organ, were measured to the nearest millimetre. Of these, the shortest was recorded. Only organs seen in their entirety on a particular scan were included. Hence not all organs were studied on each scan. Any organs that were felt to be affected by pathology, such that it would alter the dimensions, were excluded. This included mass effect within organs, e.g. liver metastasis, hydronephrosis and lung fibrosis, or outside the organ, e.g. ascites, adjacent lymph nodes or advanced malignant disease.

Measurements for stomach and bowel were not performed since their mobility and variable distension would produce inconsistent data. Neck vessels were excluded as an adequate sample of neck scans was not available, and also because coronal and sagittal scanning would be necessary to determine the most vulnerable approach.

Results

CT scans of 44 males and 27 females were reviewed. For each organ, the minimum skin to organ distance was recorded and the mean and standard deviation were calculated. The percentage of subjects who would be unprotected for each of the two proposed safety standards was calculated and are presented in the following table.

Table 14: Minimum skin to organ distances

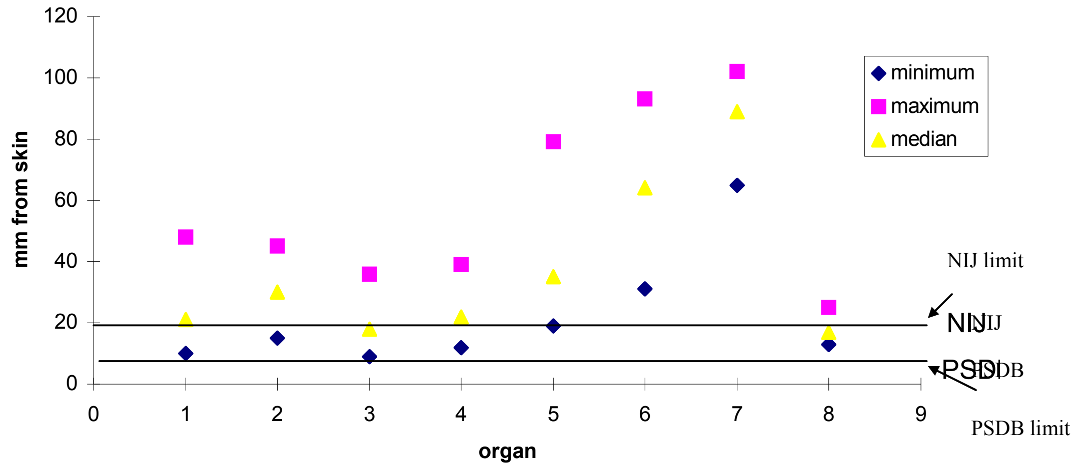
Organ	No. Female	No. Male	Total No.	Mean (mm)	Standard deviation (mm)	Total No (%) under 20mm (NIJ)
Pleura	21	35	56	22	7.9	23 (41%)
Pericardium	21	36	57	31	7.1	4 (7%)
Liver	17	29	46	19	6.3	28 (61%)
Spleen	16	24	40	23	7.0	11 (28%)
Kidney	9	18	27	37	13.0	1 (4%)
Thoracic Aorta	10	18	28	64	15.1	0
Abdominal Aorta	5	10	15	87	10.3	0
Femoral Artery	6	10	11	18	3.9	7 (64%)

There was no significant difference between the means of the minimum skin to organ distances for the male and female samples, as determined by an unpaired t test.

Table 15 shows the range of skin to organ distances for both male and female subjects and these are displayed with median values in Figure 47. It can be clearly seen that no organ would be breached up to a depth of 9 mm beneath the skin.

Table 15: Range of skin to organ distances (mm) for both male and female subjects

	pleura	pericardium	liver	spleen	kidney	thoracic aorta	abdominal aorta	femoral artery
minimum	10	15	9	12	19	31	65	13
maximum	48	45	36	39	79	93	102	25
median	21	30	18	22	35	64	89	17
n	56	57	46	40	27	28	15	11



Key:	
1	pleura
2	pericardium
3	liver
4	spleen
5	kidney
6	thoracic aorta
7	abdominal aorta
8	femoral artery

Figure 47: The range of minimum organ to skin distances for both male and female subjects

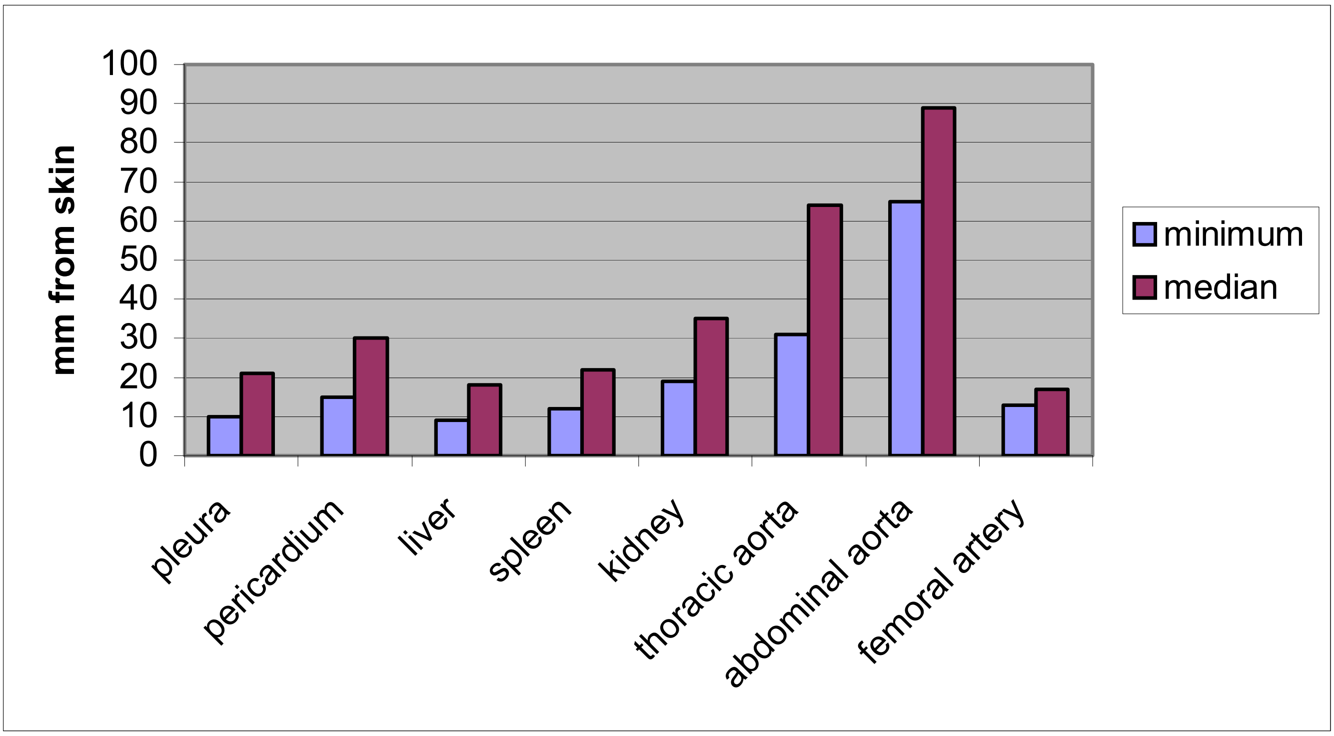


Figure 48: The minimum and median skin to organ distances are presented for the same population

Discussion

At 20 mm of knife penetration through body armour (NIJ/Metvest standard), there would have been injuries to pleura (41%), pericardium (7%), liver (61%), spleen (28%) and kidneys (4%) in these subjects. Although there was no significant difference in minimum skin to organ distances between male and female subjects, the breasts will provide some protection to the anterior thorax in females.

We have demonstrated that no organ would have been breached at the PSDB 5 mm standard for knife resistant body armour. In fact, no organ was within 9 mm of the skin.

These results may underestimate the risk to organs since after penetrating the skin a blade will continue virtually unhindered into the body with further minimal force [31]. In a real knife attack the skin and subcutaneous fat are compressed prior to penetration of the skin, so reducing the 'safety distance' [51]. In this study, we were unable to predict the amount of tissue compressibility. In a study prepared and accepted for publication after the completion of this thesis [53], an ultrasound probe was used to measure the accessibility of the internal organs from the skin, as a function of posture, and also as a function of the breathing cycle. The results were very similar to this CT study: the closest organ lies only 9 mm underneath the skin. Some degree of skin pressure was exerted by the ultrasound probe. This does not appear to have unduly altered the results [53].

CT scanning is the gold standard in assessing subcutaneous body fat [52], it can evaluate muscle mass, mediastinal, retroperitoneal and peritoneal fat in a subject. These influence the skin to organ distances. They will be influenced by age, sex and the presence of pathology.

Our subjects were patients undergoing investigations for suspected pathology. Since CT scanning involves the use of ionising radiation, it would be unethical to scan normal subjects. Hence, although grossly abnormal organs were excluded, the influence of pathology on the distribution of body fat could not be entirely excluded from this study. An abnormal anatomical situation is also produced by the method of scanning, in which the patient is positioned supine and scanned in inspiration with their arms above their head.

In the future, it would be possible to correct these shortcomings by the use of tomographic data from Magnetic Resonance Imaging (MRI). Since this does not use ionising radiation, it would be possible to scan normal volunteers and its capability to scan in different planes would ensure that the shortest distances are indeed being calculated. Future studies would also benefit from assessing the Body Mass Indices of the subjects and match them with police officer controls.

Conclusion

Computer tomographic data from this sample has demonstrated that there is inadequate protection of vital organs afforded by anti-stab body armour which allows 20 mm of knife blade penetration. However none of these organs would have been damaged at a standard allowing penetration to 5 mm.

The maximal permissible armour penetration is 9 mm. Up to this distance no internal organ would be damaged by the passage of a blade into the body.

The vulnerability of the human body to penetrating injury has been described in terms of the accessibility of the internal organs (minimum distance from the skin). It is reasonable to demand that in order to prevent serious injury, knife-resistant body armour should not allow a penetrating blade to breach the internal organs. Therefore, armour should not allow a penetrating blade to enter the body by more than the minimum skin to organ depth for the most superficial organ. In this series, the most accessible organ was the liver which was only 9 mm from the skin in the smallest subject.

The review of 500 victims of penetrating injury has demonstrated the distribution and severity of injury in real stabbing attacks. By combining the findings from both of these studies, it is now possible to describe regions of the body in terms of vulnerability to penetrating injury, hence the protective requirements of body armour for each body area.

This is presented in the next section.

PART 9: CRITERIA FOR ZONING - THE POTENTIAL ROLE IN BODY ARMOUR DEVELOPMENT

Introduction

In the two studies presented earlier, the vulnerability of the human body to stab attacks by area and the depth to which a blade can be safely pushed into the trunk were defined. By combining these studies, it is now possible to map the body into areas depicting their protection requirements.

To describe areas of the body and their relation to the location of organs, it is useful to relate to easily recognisable anatomical landmarks.

Anatomical Landmarks

The construction of a zoning system that reflects the anatomical risk to individual organs must be based on a sound understanding of the position of the organs in relation to surface anatomy. These are typically related to bony landmarks that are relatively simple to identify. The bony landmarks used for orientation are listed here and illustrated in two diagrams (Figures 49 and 50).

Angle of Louis	a bony protuberance approximately 1/3 of the way down the sternum. A finger moving to either side will fall onto the second rib. From this point, it is easy to count the ribs.
acromioclavicular joint	the tip of the shoulder.
Sternoclavicular joint	the junction of the clavicle (collar bone) with the sternum at the front of the neck.
jugular notch	the depression immediately above the sternum.
Xiphoid	the depression immediately below the sternum.
C7 vertebra	the most prominent bony protuberance at the back of the neck, other vertebrae can be counted from this point.

iliac crest	the top of the pelvis.
anterior superior iliac spine (asis)	anterior point of the iliac crest.
anterior axillary fold	lateral part of the pectoral area, lip of the anterior wall of the axilla (armpit).
posterior axillary fold	lip of the posterior wall of the axilla.

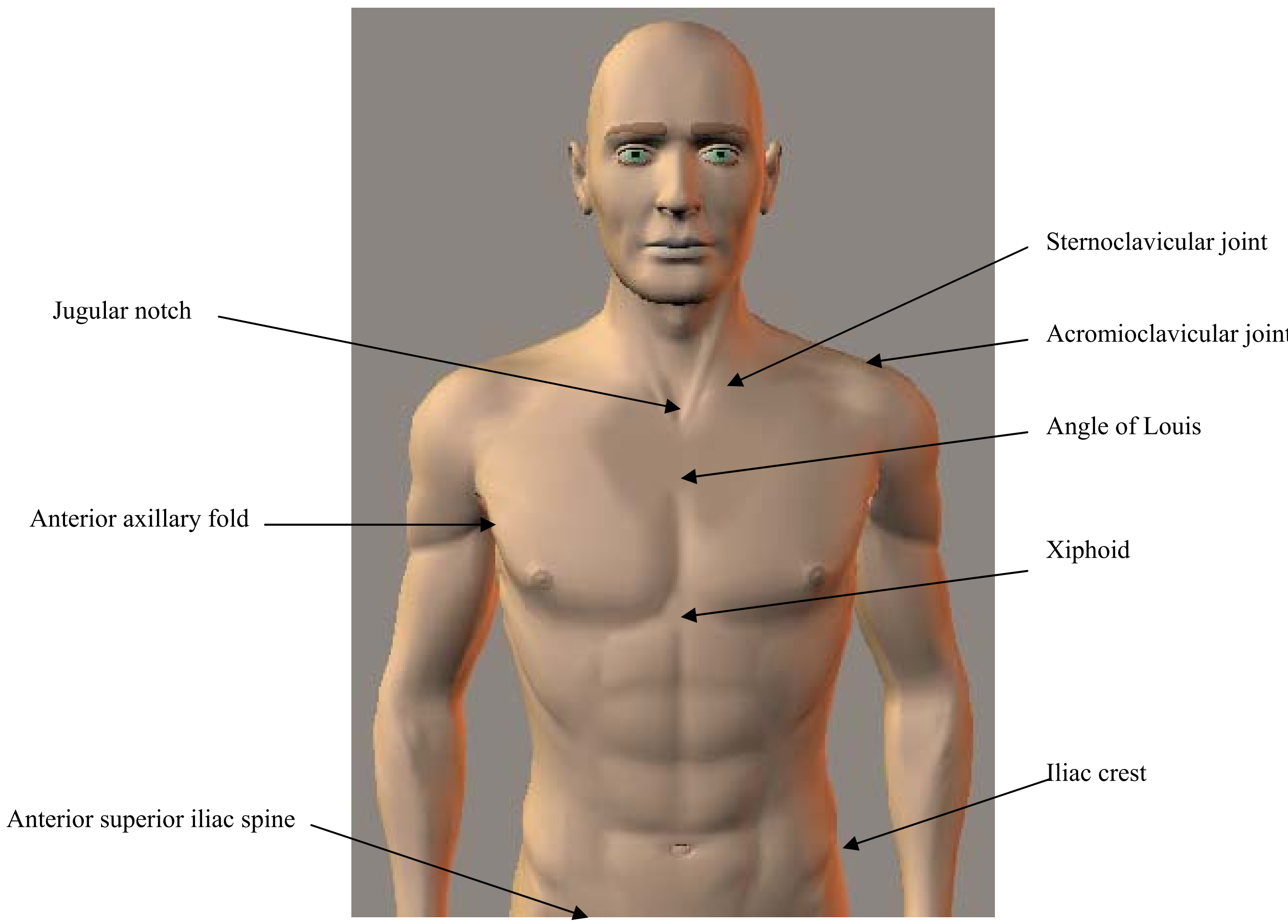


Figure 49: Anatomical landmarks (anterior)

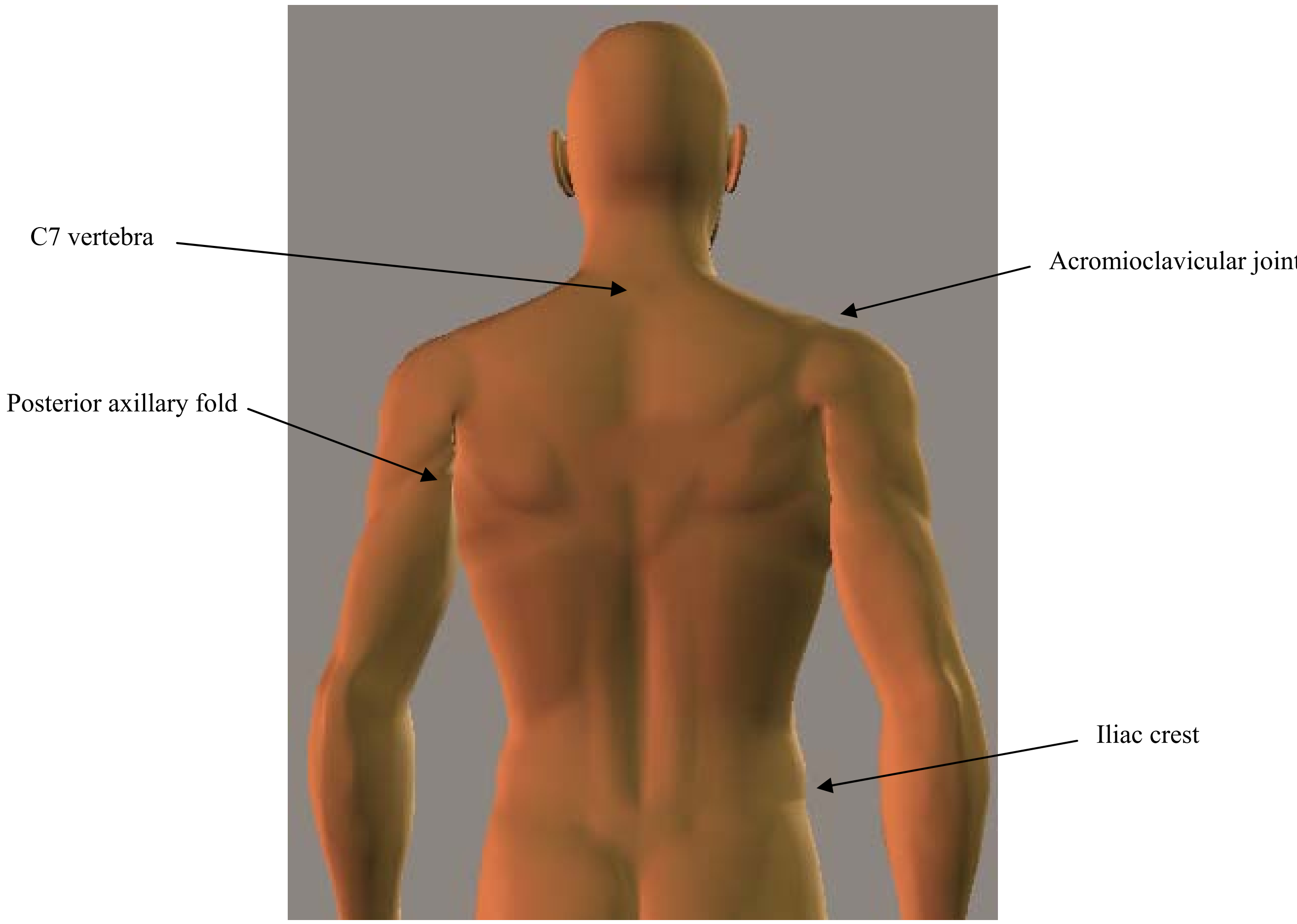


Figure 50: Anatomical landmarks (posterior)

The position of the internal organs can be described in relation to these surface anatomy landmarks. These are relatively constant for both sexes and for individuals of both large and small stature.

Table 16: The position of the organs by surface anatomy

Organ	Bony Landmarks
chest wall	vertebrae C7 -T12, all ribs, first 2 lumbar vertebrae
abdominal wall	lower rib margin to pelvic rim, bounded superiorly by the mobile diaphragm
heart	rt 3rd costal cartilage to lower border of rt 6th cartilage to left 6th rib 9cm from the midline to 2cm left of the sternum at the second rib
lungs	1st rib, lower rib margin, diaphragm
liver	from 4th rib to 2.5 cm beneath rt and central lower rib margin (max range)
femoral vessels	cross middle of groin crease
subclavian vessels	run behind and inferior to clavicle
spleen	8th to 11th rib left lateral chest wall
stomach	varies widely according to content and breathing cycle
kidney	11th rib to 12.5 cm beneath 12th rib on posterior either side of spine (5 – 15 cm from midline)
gut and mesentery	mobile, varies widely according to content, beneath the diaphragm (mobile)

Knowledge of the position of the internal organs will allow for mapping of the body into regions of varying vulnerability and corresponding protection requirements.

PART 10: PLOTTING THE REGIONAL PROTECTION REQUIREMENTS OF THE HUMAN BODY

Introduction

By combining the preceding analyses: organ vulnerability, frequency of injury to body zones (regional wound scoring)- where possible, with the estimated mortality risk for each organ injury, it is possible to determine the regional knife protection requirements more precisely.

In this approach to regional risk, I have included the factor of assailant stabbing technique, as this has great importance. Preliminary test results from the Royal Military College of Science at Shrivenham confirm that overhand stabbings tend to generate much higher energies (60-100 Joules) than underhand assaults (30-50 Joules) [34].

The protective requirements have been defined as 'maximum', 'moderate' and 'anti-slash'. These will ultimately need to be interpreted in terms of performance specifications for each category, leading to armour panels of three levels of protection. This will be addressed later.

I have elected to restrict protection to three levels. Armour constructed with more than three types of panel would likely result in a garment that would be tremendously difficult and expensive to construct and wear.

The regional protection requirements are presented here.

Table 17: Regional risk assessment for stab injury

organ	risk of death from isolated stab wound	likely stabbing technique	minimum distance from skin (mm)	approx. incidence of injury in stabbings	Average regional wound score	PROTECTION REQUIREMENT
chest wall	<<10%	under & over	N/A	60%	N/A	N/A
abdominal wall	<<10%	under & over	N/A	43%	N/A	N/A
heart	>50%	under>over	ave:31 range:15-45	5%	6	Maximum
lungs	<10%	under>over	ave:22 range:10-48	30%	5	Maximum
liver	<10%	under>over	ave:19 range:9-36	<10%	3	Maximum
femoral vessels	>10%	under>over	ave: 18 range: 13-25	<10%	4	anti-slash
spleen	<10%	under>over	ave:23 range:12-39	<10%	3	Maximum
stomach	>10%	under>over	N/A	<5%	3	Moderate
kidney	>10%	under>over	ave:37 range:19-79	<5%	5	Moderate
gut and mesentery	<10%	under>over	N/A	<10%	3	Moderate
thoracic aorta	>50%	under & over	ave:64 range:31-93	<5%	N/A	Moderate
abdominal aorta	>50%	under>over	ave:87 range:65-102	<5%	N/A	Moderate

Determining the Anti-Stab Standards

We have established that to prevent injury to the internal organs, a blade must be stopped by body armour before the tip of the blade penetrates the body wall by more than 9 mm. The organs most at risk are those enclosed by the rib cage and spine (heart, lungs, spleen, most of the liver, and thoracic aorta). The most accessible organ here is the liver: the minimum distance to the skin being 9 mm. For the 'maximal' protection standard, it would therefore be reasonable to allow penetration of the blade to 8 mm.

The area requiring 'moderate' protection lies principally over the abdomen. Within this region lie: the lower edge of the liver, the lower poles of the kidneys, the abdominal aorta, the bowel and mesentery. The most accessible of these is the kidney (19 mm). Therefore for the 'moderate' protection standard, it would be reasonable to allow penetration of the blade to 18mm.

Both these proposed anti-stab standards would be determined on test blades delivering 42 Joules of energy, a figure that is currently widely accepted to represent the energy of an average human stab attempt [25].

The 'anti-slash' protection category has been applied to regions of the body where strikes are infrequent, the energy is likely to be relatively low (underhand stabbing or slashing) and where the risk of death from a penetrating injury is low. At present no accepted test procedure exists for anti-slash protection, although this work is underway at the Royal Military College of Science [22,34].

In the next section, this concept of regional risk protection will be plotted on anatomical charts. This will provide the starting point for designing zoned body armour.

Plotting the Knife Protection Requirements of the Body

The margins of the protective zones for knife protection can now be plotted onto anatomical charts. The margins of the armour and the protective regions comprising the armour have been slightly extended to allow for the changes in organ position during the respiratory cycle, body movement of the wearer and to provide a zone of safety for angled knife attacks.

These protective zones are presented in the following diagrams. The maximum protection zones are shaded in red and the moderate protection areas in yellow. Anti-slash material might form the pattern of a tunic-like garment into which modified panels could be inserted to provide protection to the desired levels.

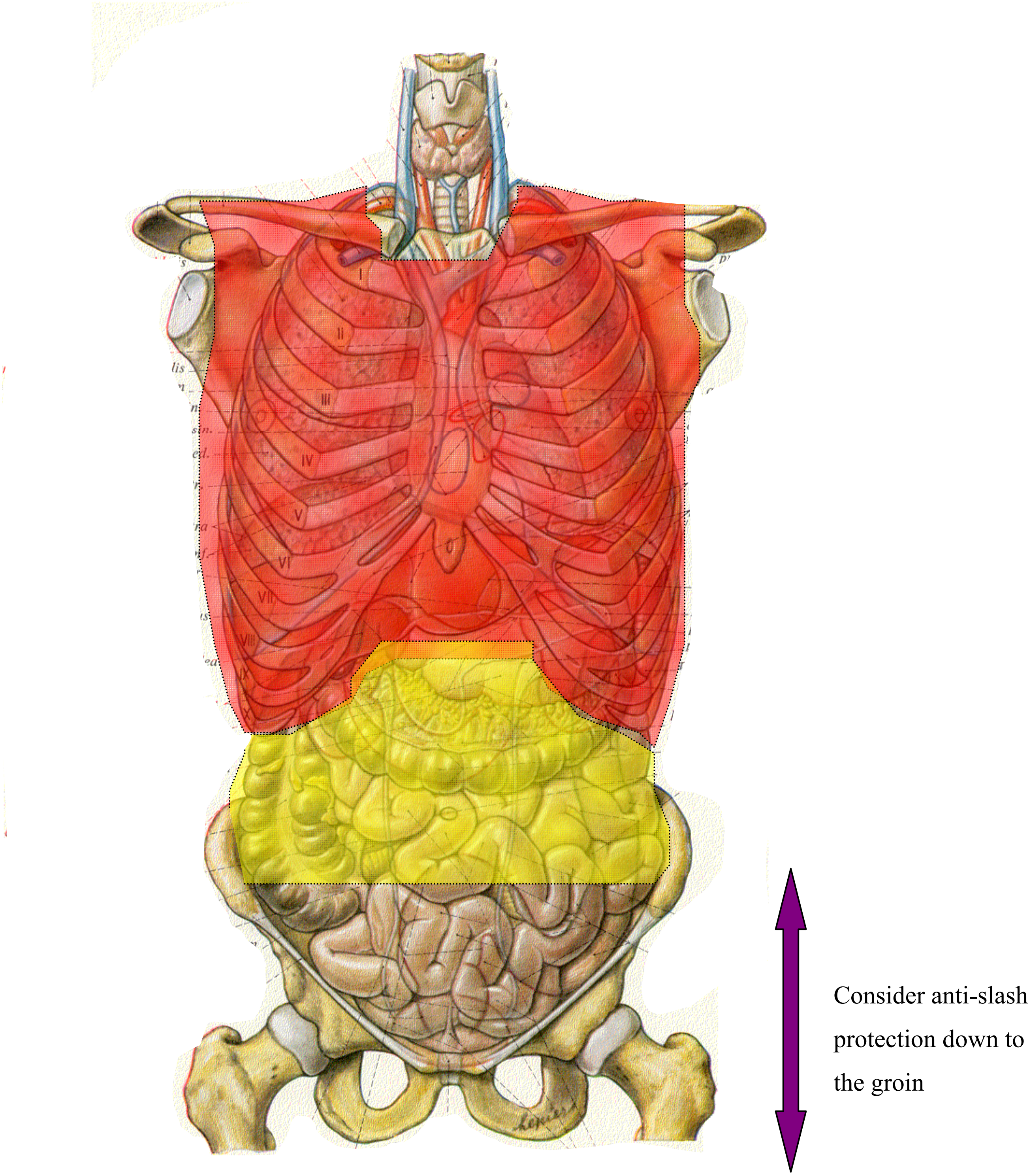


Figure 51: Armour protection zones (anterior)

References

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