

## ORIGINAL COMMUNICATION

# Wounding patterns and human performance in knife attacks: optimising the protection provided by knife-resistant body armour

A. Bleetman,<sup>1</sup> C. H. Watson,<sup>2</sup> I. Horsfall,<sup>1,2</sup> S. M. Champion<sup>1,2</sup>

<sup>1</sup>Consultant in Accident and Emergency Medicine, Honorary Senior Clinical Lecturer in Surgery, Birmingham Heartlands Hospital, West Midlands, UK; <sup>2</sup>Engineering Systems Department, Royal Military College of Science, Defence Academy UK, Shrivenham, Wiltshire, UK

**SUMMARY.** **Background** Stab attacks generate high loads,<sup>1</sup> and to defeat them, armour needs to be of a certain thickness and stiffness.<sup>2,3</sup> Slash attacks produce much lower loads and armour designed to defeat them can be far lighter and more flexible.

### Methods and subjects

*Phase 1: Human performance in slash attacks:* 87 randomly selected students at the Royal Military College of Science were asked to make one slash attack with an instrumented blade on a vertically mounted target. No instructions on how to slash the target were given. The direction, contact forces and velocity of each attack were recorded. *Phase 2: Clinical experience with edged weapon attacks:* The location and severity of all penetrating injuries in patients attending the Glasgow Royal Infirmary between 1993 and 1996 were charted on anatomical figures.

### Results

*Phase 1:* Two types of human slash behaviour were evident: a ‘chop and drag’ blow and a ‘sweep motion’ type of attack. ‘Chop and drag’ attacks had higher peak forces and velocities than sweep attacks. Shoulder to waist blows (diagonal) accounted for 82% of attacks, 71% of attackers used a long diagonal slash with an average cut length of 34 cm and 11% used short diagonal attacks with an average cut length of 25 cm. Only 18% of attackers slashed across the body (short horizontal); the average measured cut length of this type was 28 cm.

The maximum peak force for the total sample population was 212 N; the maximum velocity was 14.88 m s<sup>-1</sup>. The 95 percentile force for the total sample population was 181 N and the velocity was 9.89 m s<sup>-1</sup>.

*Phase 2:* 431 of the 500 patients had been wounded with edged weapons. The average number of wounds sustained by victims in knife assaults was 2.4. The distribution of wounds by frequency and severity are presented.

**Conclusions** Anti-slash protection is required for the arms, neck, shoulders, and thighs. The clinical experience of knife-attack victims provides information on the relative vulnerabilities of different regions of the body. It is anticipated that designing a tunic-type of Police uniform that is inherently stab and slash resistant will eventually replace the current obvious and often bulky extra protective vest.

Attempts at making a combined garment will need to be guided by ergonomic considerations and field testing. A similar anatomical regional risk model might also be appropriate in the design of anti-ballistic armour and combined anti-ballistic and knife-resistant armour.

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A. Bleetman, Consultant in Accident and Emergency Medicine, Honorary Senior Clinical Lecturer in Surgery, Birmingham Heartlands Hospital, 32 Rothwell Drive, Solihull, West Midlands, B91 1HG, UK.

Correspondence to: A. Bleetman, E-mail: [bleetman@enterprise.net](mailto:bleetman@enterprise.net)

## INTRODUCTION

Examination of the mechanics of human slash attacks together with a review of wounding in real-life knife attacks will allow design of ergonomically acceptable armour that confers protection from stab

attacks over high risk areas of the torso, together with protection from slash attacks over other parts of the human anatomy vulnerable to this type of attack.

Modern knife-resistant body armour issued to the Police is designed to prevent serious injury or death from penetration of a knife blade deep into the human body by stabbing. The specification for the level of protection afforded by the armour was derived from tests which simulated the energies generated by human stabbing attempts with test blades.<sup>1</sup> The maximal permissible depth of penetration of a blade through armour into the human body was arrived at by CT and ultrasound studies.<sup>4-6</sup>

Many injuries caused by edged weapons seen in clinical practice are from a slash-type of attack, and not from stabbing. Slash attacks will often be disfiguring and can be life-threatening if they involve blood vessels lying close to the skin, particularly in the neck, the groin, and upper limbs. This contrasts with stabbing assaults in which the most serious threat is deep penetration into the internal organs within the trunk. Thus far, there has been little consideration of the type and distribution of knife wounding to the body in real-life knife attacks in determining the areas of the body requiring cover by knife-resistant armour.

Stab attacks generate high loads,<sup>1</sup> and to defeat them armour needs to be of a certain thickness and stiffness.<sup>2,3</sup> Modern stab-resistant body armour systems generally only cover the chest and upper abdomen, where most of the major organs are found. It is ergonomically impractical to cover and protect areas such as groin, upper arms and neck with current stab-resistant armour.

Slash attacks produce much lower loads and armour designed to defeat them can be far lighter and more flexible. Stab-resistant armour will defeat slash attempts, but slash-resistant armour will not offer substantial anti-stab protection.

The ideal knife-resistant armour would offer protection from stab attacks over high risk areas of the torso together with protection from slash attacks over other parts of the human anatomy vulnerable to this type of attack. Optimising the body coverage of both anti-stab and anti-slash protective areas in knife-resistant armour will provide the wearer with a garment that offers the best in terms of wearability, ergonomic performance and protection.

Knowledge of wounding patterns in real-life stabbing and slashing knife attacks seen in clinical practice, combined with knowledge of the loads imparted in these attacks, will facilitate improvements in the design and relevance of body armour.

## METHODS

This paper comprises two separate parts: the first deals with assailant performance in simulated slash attacks; the second with the vulnerability of the human body to real life knife attacks.

## EXPERIMENTAL PROCEDURE

### Phase 1. Human performance in slash attacks

87 randomly selected students from both military and civilian courses at the Royal Military College of Science participated in the study. This group consisted of both male and female volunteers between the ages of 20 and 55 years. Each volunteer stood about a metre in front of a target and was asked to make one slash attack with an instrumented blade. No instructions on how to slash the target were given. The direction of each attack was recorded.

A Kevlar<sup>®</sup>/elastomer target was mounted vertically. A witness sheet of white cartridge paper was attached to the front of the target, to record the distance that the knife was in contact with the target and the direction of each slash (Fig. 1). The instrumented blade measured the contact forces and contact time during the attack. The velocity of the slash in metres per second ( $\text{m s}^{-1}$ ) was calculated from the length (metres) of the slash measured from the paper and the time to make the slash (seconds).



**Fig. 1** Volunteer slashing a vertical target with an instrumented blade.

## Phase 2. Clinical experience with edged weapon attacks

A computerised, retrospective search was carried out on 500 consecutive patients attending the Accident and Emergency department of the Glasgow Royal Infirmary between 1993 and 1996 following penetrating trauma. Patients were identified from their discharge diagnosis. Scottish Trauma Audit Group (STAG) 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 h following trauma).

The location of all penetrating injuries described or sketched in the clinical records of each patient was marked on one of four anatomical figures (right, left, anterior and posterior projections). Each anatomical figure was zoned between prominent bony landmarks and other obvious surface anatomy landmarks. Each marked wound was colour-coded according to perceived severity. The severity of wounding could not be rated by conventional injury severity scoring systems as many patients had not been formally scored by the trauma registry at the time of examination of the hospital records.<sup>7</sup> The following arbitrary severity scoring criteria were used:

- *Minor* – not a threat to life or limb, slash-type injuries.
- *Major* – wounds that resulted in major blood loss, threat to life, tendon damage, bone involvement, major neurovascular injury or permanent major cosmetic deformity.
- *Devastating* – fatal or near-fatal (patients in the near-fatal category arrived at hospital in cardiac arrest or in a moribund state).

The number and distribution of wounds were analysed.

## RESULTS

### Phase 1. Human performance in slash attacks

#### *Type of attack*

Two types of human slash behaviour were evident. The first was a 'chop and drag' type of blow, which showed an initial sharp peak followed by a drop in force and a second broader peak. The second was a 'sweep motion' type of attack whose force profile showed less of an initial peak and a steady increase in force up to a maximum. 'Chop and drag' attacks had higher peak forces and velocities than sweep attacks. 26% of attacks were 'chop and drag', 74% were 'sweep motion'.

#### *Angle of attack*

Shoulder to waist blows (diagonal) accounted for 82% of attacks, 71% of attackers used a long diagonal slash with an average cut length of 34 cm and 11% used short diagonal attacks with an average cut length of 25 cm. Only 18% of attackers slashed across the body (short horizontal) and the average measured cut length of this type was 28 cm.

There were 8 female subjects in the trial, 9.2% of the sample population. Three female subjects attacked the target with a long diagonal slash, 4.2% of the total sample for long diagonal attacks and five used a short horizontal slash accounting for 30% of the total number of horizontal attacks.

It was not possible to prove that gender influenced the choice of test direction or angle of attack from the numbers of female subjects in the trial.

Five test subjects were left-handed, all were male and at 5.74% of the total sample population equated with typical numbers of left-handed people found within the populace at large.

Four of the left-handed volunteers attacked with a long diagonal blow with only one subject attacking with a short horizontal blow.

#### *Force data analysis*

The maximum peak forces and velocities from each test were grouped into one of the three directions described above: long diagonal, short diagonal or horizontal. The maximum and average peak forces and velocities for the sample population are presented in Table 1.

The maximum peak force for the total sample population was 212 N and this was achieved by a male subject using a long diagonal attack. The maximum velocity of 14.88 m s<sup>-1</sup> was measured from a different male subject. The average peak force for the total sample population was 107 N and the average velocity was 5.94 m s<sup>-1</sup>. The 95 percentile force for the total sample population was 181 N and the velocity was 9.89 m s<sup>-1</sup>.

### Phase 2. Clinical experience with edged weapon attacks

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 or air gun injuries.

431 of the 500 patients had been wounded with edged weapons. Of these, 405 were male and 26 female.

**Table 1** Mean, maximum and 95 percentile force and velocity data classified by type and direction of attacks

Direction of attack	% of sample population	Force (N)			Velocity (m s <sup>-1</sup> )		
		Mean peak force	95 percentile Force	Maximum peak force	Mean velocity	95 percentile Velocity	Maximum velocity
Long diagonal	71%	114	179	212	6.03	10.55	14.88
Short diagonal	11%	106	170	173	5.05	6.70	7.00
Short horizontal	18%	102	161	188	6.09	11.21	13.30
All test directions	100%	107	175	212	5.94	10.57	14.88
<i>Type of attack</i>							
Chop and drag	26%	124	180	212	6.44	11.07	13.30
Sweep	74%	97	152	178	5.88	10.10	14.88

### Severity of stab wounds

The distribution of wounds for knife attacks by severity is presented. The average number of wounds sustained by victims in knife assaults was 2.4 (see Table 2).

The wounds are presented by region and severity in Table 3.

To demonstrate the probability of sustaining a wound of a given severity in a particular anatomical location in an edged weapon assault, Table 4 is presented in percentages.

**Table 2** Severity of wounds

Severity of wound	Number	% of all wounds
Minor, slash-type wounds	656	63.3
Major	301	29
Devastating	80	7.7
Total	1037	100

**Table 3** Distribution of wounds by region and severity

Region	Minor (slash) 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

## DISCUSSION

### Slash attacks

In this experiment, volunteers were asked to attack a static, vertical target. It is reasonable to assume that in real life knife attacks, both parties would be moving – human conflict being a dynamic process. Previous studies of human stabbing attempts suggest that the assailant's method of delivering a thrust with a blade will influence the amount of energy delivered to the target.<sup>8</sup> Previous work also suggests that there are some differences between the forces measured on an instrumented blade and those generated in live human stabbing attempts.<sup>9</sup> Notwithstanding these, the combined test data showed that typical slash velocities were in the range 6–10 m s<sup>-1</sup>, similar to those seen in the previous stabbing work.<sup>10</sup> The 95th percentile showed that the volunteers in the sample population attacked with peak force loads of below 180 N, and the mean peak loads were less than 115 N. These slash peak loads can be compared to the 95th percentile peak loads of 800 N measured in human stabbing attacks;<sup>1</sup> peak forces of slashing attacks only reached approximately 25% of the loads measured in stabbing attacks. This suggests that body armour could be designed to incorporate adequate protection against slash attack in areas such as the groin and neck without needing to match the level of protection afforded by stab-proof armour.

As current anti-stab armours are generally complex multi-layer systems, they can be bulky and relatively inflexible, inhibiting movement and reducing wearability. Adequate slash-only protection could be offered using fewer layers of aramid, designed to be similar in heat loads and comfort to a heavy cotton material. Fewer layers would increase the flexibility of the protection system in areas of the body vulnerable to slashing attack.

**Table 4** Distribution of wounds by region and severity in percent

Region	% of all minor (slash) 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

### Victims of human knife attacks

From clinical practice it is evident that the majority of all fatal stab wounds involve the chest.<sup>11,12</sup> The chest is largely covered and protected by modern body armour, which is therefore likely to prevent most deaths from stabbing. However, knife wounds to the chest comprised less than a quarter of knife wounds in the victims of edged weapon assault described in this study. Therefore, most stab wounds will not be prevented by current armour systems. The vulnerability of the human body to edged weapon assaults has been shown.

The distribution of wounds, particularly the major and devastating wounds, would suggest that the majority of knife assailants are confrontational and right handed. This was confirmed in the experimental trial where, without guidance or instructions, the majority of subjects also chose to attack with the knife in their right hand. The high incidence of serious injury to the left loin is perhaps influenced by the defensive stance of the victim, who has presented the non-dominant side of the body towards the assailant. The mechanics of fighting and the skills of the combatants will influence the distribution and severity of wounds on the body.

It is clear from the distribution of wounds in real-life knife attacks that anti-slash protection is required for the arms, neck, shoulders, and thighs. It will clearly not be possible to provide armour of any standard to protect the face and head for routine wear.

### CONCLUSIONS

The experimental work on human slash attempts provides guidance on the required protective properties needed by anti-slash armour. The protective properties of anti-stab armour are already known.<sup>13,14</sup>

The clinical experience of knife-attack victims provides information on the relative vulnerabilities of different regions of the body. Slash wounds are more common than stab-type wounds on the scalp, face, neck, limbs and buttocks. The entire body cannot be protected by knife-resistant armour but the risk of injury can be reduced within ergonomic constraints. Light, flexible anti-slash material can be incorporated into the sleeves, collars and shirt-tails of police uniforms. This might be in the form of a cover in which armour panels made to full anti-stab specification over the areas of the human body at risk from major and devastating stab assaults could be inserted. Knowledge of the frequency and severity of wounding on the body will facilitate anatomical regional risk scoring, which will translate into zones of varying protective properties in the final garment.

Incorporating anti-slash and anti-stab protective areas into one garment will also provide the wearer with a garment of clothing that offers optimal protection, and not an item of personal protective equipment that is obvious to all. It is anticipated that designing a tunic-type of Police uniform that is inherently stab and slash resistant will eventually replace the current obvious, and often bulky, extra protective vest.

Attempts at making a combined garment will need to be guided by ergonomic considerations and field testing. A similar anatomical regional risk model might also be appropriate in the design of anti-ballistic armour and combined anti-ballistic and knife-resistant armour. This will need to consider the local pattern of wounding in real-life armed assaults.

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