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Variability of simulants used in recreating stab events

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ABSTRACT

Forensic investigators commonly use simulants/backing materials to mount fabrics and/or garments on when recreating damage due to stab events. Such work may be conducted in support of an investigation to connect a particular knife to a stabbing event by comparing the severance morphology obtained in the laboratory to that observed in the incident. There does not appear to have been a comparison of the effect of simulant type on the morphology of severances in fabrics and simulants, nor on the variability of simulants. This work investigates three simulants (pork, gelatine, expanded polystyrene), two knife blades (carving, bread), and how severances in the simulants and an apparel fabric typically used to manufacture T-shirts (single jersey) were affected by (i) simulant type and (ii) blade type. Severances were formed using a laboratory impact apparatus to ensure a consistent impact velocity and hence impact energy independently of the other variables. The impact velocity was chosen so that the force measured was similar to that measured in human performance trials. Force–time and energy–time curves were analysed and severance morphology (y, z directions) investigated. Simulant type and knife type significantly affected the critical forensic measurements of severance length (y direction) in the fabric and 'skin' (Tuftane). The use of EPS resulted in the lowest variability in data, further the severances recorded in both the fabric and Tuftane more accurately reflected the dimensions of the impacting knives.

1. Introduction

The most common method of killing in the United Kingdom is through the use of sharp instruments (39% of all homicides in 2008/2009), with the most common type of sharp instrument weapon used being knives (7% of violent crimes) [1,2]. An analysis of non-firearm homicides in London revealed that approximately 80% of stabbings are to the torso of a victim [3], which is commonly covered by a T-shirt. Therefore, flesh and fabrics are both likely to be damaged by the blade during an attack.

Simulants/backing materials that represent the human body are widely used in forensic reproductions of stab events. Information from such laboratory investigations can reportedly be informative when investigating serious crimes involving stab wounds [4,5]. However, a systematic investigation of the effect of simulant type on potential evidence obtained does not appear to have been reported in the literature, nor does there appear to have been an investigation regarding the variability of data obtained using a single simulant type and among different simulants.

Standard test methods used for stab testing are limited to the design, development and testing of body armour and protective clothing. A method commonly used for testing body armour is that produced by the Home Office Scientific Development Branch (HOSDB). *HOSDB Body Armour Standards for UK Police Part 3: Blade and Spike Resistance* details types of weapons (knives, spikes), test conditions, and a backing ensemble to be used behind the body armour being tested [6]. The backing ensemble comprises of a complex arrangement of (i) four layers of Neoprene (6 mm thick; RA110), (ii) one layer of Plastazote (30 mm thick; 33 kg/m^3) and (iii) two layers of rubber (6 mm thick; 2494D) [6]. Other simulants/witnesses/backing materials used in standard methods involving testing with sharp implements include (i) paper witness (Polyart; 80 g/m^2) located between a body armour designed to provide protection from slash attacks and a metallic backing plate with which an electrical signal can be detected on penetration [7], (ii) metal support [8], (iii) rigid base covered with EVA foam (14 mm thick; 50 kg/m^3) [9] and (iv) mixture of fine white maize flour and liquid paraffin [10].

Human variability both within a population and an individual with respect to the use of a simulant are acknowledged. Use of various simulants for recreating stab events have been reported in the peer-reviewed forensics literature including foam wrapped punch bags [11]; pork [12–14]; gelatine [15]; aramid thermoplastic composite sheet (5.5 mm thick) and Roma Plastilina [16,17]; silicone (1.5 mm), closed cell polyethylene foam (30 mm) and open cell polyethylene foam (150 mm) [18]; and cadavers [4,19]. Pork

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and gelatine are probably the most commonly used simulants in wider forensic investigations, and pork skin is widely accepted as being a suitable model for human skin however, data published by Brett et al. suggested that the force to penetrate pig skin was much higher than that to penetrate human skin [20]. Pork is often used in preference to gelatine due to the time required to manufacture gelatine blocks, and the time limited nature of gelatine which generally should be used the day after manufacture. However, as pork is a biomaterial, concerns have been raised with respect to it's variable properties which might affect performance as a simulant [e.g. 21].

With respect to a fabric layer, or garment placed in front of the simulant to investigate the morphology of severances to fabrics during a stab event, it is well recognised that laundering fabric affects the physical and mechanical properties of fabric [22]. Dimensional stability and minimisation of variation of properties of fabrics can be achieved by laundering. In textile science, it is generally accepted that fabrics exposed to six laundering cycles are stabilised [22]. The identification of the source (knife type) of damage was affected by laundering condition for apparel fabrics; identification was easier in non-laundered fabrics [18]. Therefore, new fabrics should not be used in the reproduction of stab events that have occurred on worn apparel (which is likely to have been laundered).

That blade morphology affects the resulting severances in fabrics is also recognised in the literature. Blunt knives (tips and/or blades) and knives with scalloped edges result in more fabric distortion and the severances are frayed compared to smooth and sharper blades [18,23,24]. Kitchen knives were used in 39% of stabbings that occurred in Stockholm between 1983 and 1993 [25]. The presence or absence of a support and the stiffness of the support is also known to affect the severance [23]; however, comparison of different supports does not seem to have been reported.

Therefore, the aim of this work was to compare different simulants/backing materials and to investigate a simulant/backing material for use in laboratory reproductions of knife attacks that *provides a consistent response*. The aim was not to investigate simulants that represent the human body however; two of the simulants used are reported in the literature as simulating human skin and flesh (i.e. pork, gelatine). The simulants used were (i) gelatine, (ii) pork, and (iii) expanded polystyrene foam. Two knife blades (carving, bread) and an apparel fabric typically used to manufacture T-shirts (single jersey) were used. Force–time and energy–time data were collected and were examined together with depth of penetration into simulant and morphology of severances in the fabric.

2. Materials and methods

2.1. Fabric

The fabric used was a 100% cotton single jersey[1]; this type of fabric is used to manufacture T-shirts, and hence is commonly worn by victims of a stabbing event to the torso. The fabric was tested in a dimensionally stable state by laundering for 6 cycles according to section 8A of BS EN ISO 6330/A1: 2009 [26]. The fabric was not dried between cycles, but dried flat after the sixth cycle according to procedure C of the same standard. Specimens ($n = 5$; 120 mm × 120 mm) were cut from the pre-treated fabrics according to BS EN 12751: 1999 [27]. All specimens were impacted on the technical face with the wale direction aligned with the blade. Mass per unit area and thickness data before and after pre-treatment are given in Table 1, and demonstrate the low variability of the fabric investigated.

2.2. Simulants

The single jersey fabric was tested mounted on three simulants (120 mm × 120 mm × 120–150 mm) (i) 20% gelatine (porcine origin), (ii) expanded polystyrene (EPS; Jablite ESP70[2]) and (iii) deboned rolled pork shoulder joint (with skin). Testing was blocked by simulant due to the time sensitive nature of the gelatine and pork. A 'skin' of polyurethane film (~1.2 mm thick; TuftaneTFL-1EA[3]) was placed in front of the gelatine and EPS simulants.

Table 1
Mass per unit area and thickness data for fabric.

	Mass per unit area[a] (g/m^2)			Thickness[b] (mm)		
	Mean	s.d.	CV (%)	Mean	s.d.	CV (%)
New	162.6	1.8	1.11	0.78	0.01	1.02
Laundered 6 cycles	201.3	3.3	1.64	0.98	0.02	2.46

[a] [28].
[b] [29].

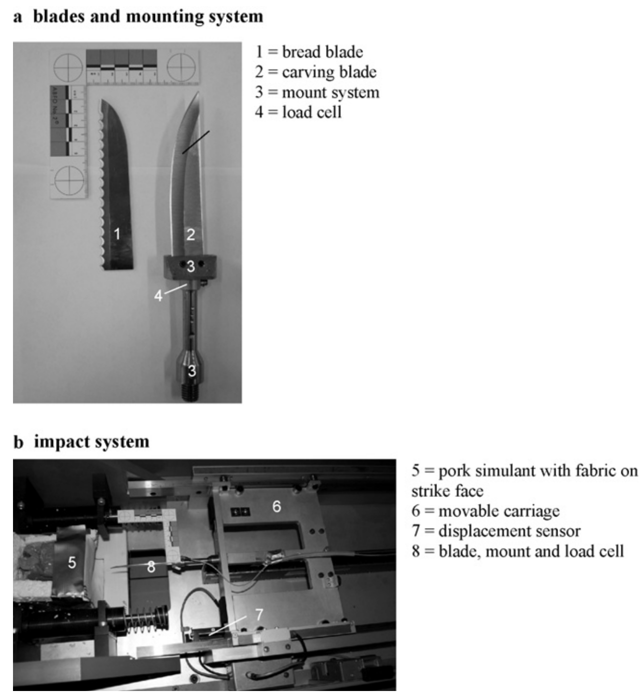

Fig. 1. Experimental apparatus.

2.3. Blades

Knives that might be commonly available in a domestic situation were chosen[4] (i) a bread knife and (ii) a carving knife. The blades were cut from the knives so that both were of similar dimensions (Fig. 1).

2.4. Impact apparatus

An Imatek horizontal impact apparatus was used for all testing (Fig. 1).[5] Each blade was mounted in a customised grip fitted with a Kistler 9011A quartz load washer (range = 15 kN, sensitivity = 4.11 pC/N) (Fig. 1). Testing was conducted at an impact velocity of 2 m/s, full scale deflection of 1.5 kN, event capture time of 400 ms and a resolution of 5000 points for the event. A pre-trigger of 10% ensured that all data were collected. Data were displayed as force–time and energy–time using ImpAcq7 impact analysis v2.10.

2.5. Analysis

After impact, photographs were taken of the severances in the fabric, 'skin' and simulant using a Nikon D3000 digital camera fitted with a Nikon DX 18–55 mm lens camera and an ABFO no. 2 photomacrographic scale. The effect of simulant and blade type on the severance size (y direction fabric, Tuftane, stimulant; z simulant) and on the force–time and energy–time data was explored using analysis of variance (ANOVA) and Tukey's tests (SPSS Statistics 17.0).

[1] Supplied by FabricUK.com, Birmingham, UK.
[2] B&Q, Swindon, UK.
[3] Permali Gloucester Limited, Gloucester, UK.
[4] Asda, Swindon, UK.
[5] Imatek Ltd., Nup End Business Centre, Old Knebworth, Herts, SG3 6QJ, UK.

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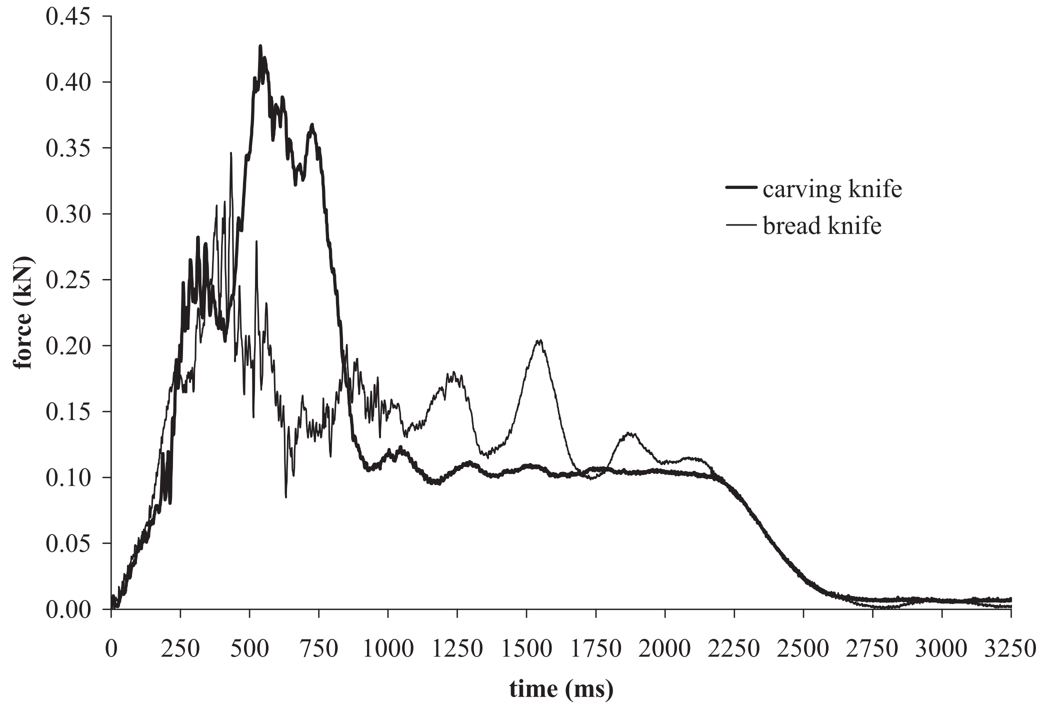

Fig. 2. Typical force–time data.

Table 2
Summary data.

	Maximum force (kN)			Maximum energy (J)		
	Mean	s.d.	CV (%)	Mean	s.d.	CV (%)
(a) Maximum force and energy data						
Carving blade						
Pork	0.73	0.59	80.82	19.84	18.16	91.53
Gelatine	0.47	0.09	19.15	10.63	1.44	13.55
EPS	0.30	0.10	33.33	8.69	1.96	22.55
Bread blade						
Pork	0.21	0.11	52.38	5.85	4.13	70.60
Gelatine	0.29	0.09	31.03	7.75	0.18	2.32
EPS	0.37	0.05	13.51	8.69	0.19	2.19
	Fabric (mm)			Tuftane (mm)		
	Mean	s.d.	CV (%)	Mean	s.d.	CV (%)
(b) Severance dimensions in fabric and Tuftane						
Carving blade						
Gelatine	1.40	1.67	119.29	4.20	2.17	51.67
EPS	22.40	1.69	7.54	21.00	0.71	3.38
Bread blade						
Gelatine	16.00	8.52	53.25	18.50	2.38	12.86
EPS	18.80	1.79	9.52	20.40	1.14	5.59
	Maximum length (mm)			Maximum depth (mm)		
	Mean	s.d.	CV (%)	Mean	s.d.	CV (%)
(c) Severance dimensions in simulant						
Carving blade						
Gelatine	9.00	8.57	95.22	24.80	18.03	72.70
EPS	28.80	3.27	11.35	57.60	3.85	6.68
Bread blade						
Gelatine	17.50	3.79	21.66	37.00	7.07	9.11
EPS	29.20	5.10	17.47	59.00	4.06	6.88

3. Results

Typical force–time curves are given in Fig. 2. Data obtained is summarised in Table 2. Neither blade penetrated specimens (fabric, simulant) that used pork as a simulant; therefore severance dimensions were not available for analysis. Mean force data varied 210–730 N and was similar to that measured in human participant trials by Kemp et al. (314 ± 133 N) [18].

3.1. Force and energy data

Mean measured force was significantly affected by the knife type, although only slightly, but not by the type of simulant used ($F_{1,24} = 5.08$, $p \leq 0.05$; $F_{2,24} = 0.67$, p = NS). The highest mean force was measured for the carving knife compared to the bread knife (0.50 kN; 0.29 kN). Neither knife type nor simulant affected the maximum energy measured ($F_{1,24} = 4.03$, p = NS; $F_{2,24} = 0.67$, p = NS).

Data gathered using pork as a simulant was the most variable (CV = 52.38–91.53%). For both force and energy, the lowest variability was observed for gelatine/carving knife (CV = 19.15%; CV = 13.55%) and for EPS/bread knife (CV = 13.51%; 2.19%).

3.2. Severance data

The type of simulant and knife blade used affected the severance lengths measured in the fabric and Tuftane layers (fabric $F_{1,16} = 7.13$, $p \leq 0.05$; $F_{1,16} = 3.40$, $p \leq 0.001$: Tuftane $F_{1,15} = 143.51$, $p \leq 0.001$; $F_{1,15} = 77.03$, $p \leq 0.001$). Simulant type, but not knife type, affected the severance length measured in the simulant ($F_{1,15} = 36.28$, $p \leq 0.001$; $F_{1,15} = 2.90$, p = NS). Severance lengths in the fabric, Tuftane and simulant were longer for EPS and more similar to knife blade dimensions when compared with gelatine. However knife blade type affected the fabric and Tuftane severance lengths differently for the two simulants. For severance lengths in the fabric and Tuftane mounted on EPS, the carving knife resulted in a higher dimension; when gelatine was used the bread knife resulted in the highest dimension (fabric $F_{1,16} = 19.53$, $p \leq 0.001$; Tuftane $F_{1,15} = 91.11$, $p \leq 0.001$). Knife type did not affect severance length in the simulant differently between the two simulants ($F_{1,15} = 2.40$, p = NS).

Severance depth in the simulant was not affected by the knife type, but was affected by the simulant type ($F_{1,15} = 2.07$, p = NS; $F_{1,15} = 33.63$, $p \leq 0.001$). For both types of knives, severance depth was greatest in EPS compared to gelatine.

The severances were of a similar nature to those reported in the literature, e.g. Kemp et al. [18]. For the dimensions that can be described as critical in forensics recreations, i.e. severance length in the fabric and 'skin' (y direction), the lowest variability was observed for both knives when EPS was used as a simulant/backing material (fabric CV = 7.54–9.52%; Tuftane CV 3.38–5.59%).

4. Discussion

In this work impact mass, velocity and therefore energy were constant among all tests; variables considered were knife type and simulant type. The primary aim of this research was to investigate how simulants might affect forensic evidence gathered during reproduction of stab attacks and to identify simulants that would provide a consistent response to an impact. Thus there are two points that warrant discussion (i) comparison of simulants, and (ii) variability of simulant types.

In this work, neither knife penetrated the fabric mounted in front of pork; therefore pork was not considered to be a suitable simulant. Further, with respect to the measurement of maximum force and energy during the impact event the use of pork resulted in the highest variability.

With respect to the remaining two simulants, both simulant type and knife type affected the critical forensic measurements of severance length in the fabric and 'skin' (Tuftane). The use of EPS resulted in the lowest variability of data, further the severances recorded in both the fabric and Tuftane when EPS was used more accurately reflected the dimensions of the impacting knives when compared to gelatine.

5. Conclusions

This work suggested that of the three simulants/backing materials investigated, EPS is the optimum solution. The data obtained for EPS had the lowest variability and more reflected the actual dimensions of the knives used during the impact testing. Further EPS is easy to obtain, prepare and use; relatively inexpensive; and is not a time sensitive solution. However, it must be emphasised that EPS does not replicate the response of human tissue.

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References

[1] K.F. Smith, Homicides, firearm offences and intimate violence 2008/09 – supplementary volume 2, in: Crime in England and Wales 2008/09, Home Office, London, UK, 2010.
[2] S.C. Roe, Violent and sexual crime, in: Crime in England and Wales 2008/09, Home Office, London, UK, 2010.
[3] J.M. Henderson, S.E. Morgan, F. Patel, M.E. Tiplady, Patterns of non-firearm homicide, Journal of Clinical Forensic Medicine 12 (2005) 128–132.
[4] M. Green, Stab wound dynamics – a recording technique for use in medico-legal investigations, Journal of the Forensic Science Society 18 (1978) 161–163.
[5] T. Ohshima, Diagnostic value of "superficial" stab wounds in forensic practice, Journal of Clinical Forensic Medicine 12 (1978) 32–35.
[6] J. Croft, D. Longhurst, HOSDB Body Armour Standards for UK Police, Part 3: Blade and Spike Resistance, Home Office Scientific Development Branch, St. Albans, UK, 2007.
[7] C. Malbon, J. Croft, HOSDB Slash Resistance Standard for UK Police, Home Office Scientific Development Branch, St. Albans, UK, 2006.
[8] British Standards Institution, BS EN 1082-3: 2000 Protective Clothing – Gloves and Armguards Protecting Against Cuts and Stabs by Hand Knives Part 3: Impact Cut Test for Fabric, Leather and Other Materials, British Standards Institution, London, UK, 2000.
[9] British Standards Institution, BS EN 381-1: 1999 Protective Clothing for Users Of Hand-Held Chainsaw, Part 1: Test Rig for Testing Resistance to Cutting By a Chain Saw, British Standards Institution, London, UK, 1999.
[10] British Standards Institution, BS EN ISO 13990: 2003 Protective Clothing – Aprons, Trousers and Vests Protecting Against Cuts and Stabs by Hand Knives, British Standards Institution, London, 2003.
[11] S.A. Miller, M.D. Jones, Kinematics of four methods of stabbing: a preliminary study, Forensic Science International 82 (1996) 183–190.
[12] S.N. Jones, L. Nokes, S. Leadbeatter, The mechanics of stab wounding, Forensic Science International 67 (1994) 59–63.
[13] M.N. Kaatsch, C. Mehrens, M. Nietert, The reproducible stab wound, Rechtsmedizin 3 (1993) 63–67.
[14] J. Kieser, V. Bernal, P. Gonzalez, W. Birch, M. Turmaine M, I. Ichim, Analysis of experimental cranial wounding from screwdriver trauma, International Journal of Legal Medicine 122 (2008) 179–187.
[15] S. Pollak, Medical criminalistics, Forensic Science International 165 (2007) 144–149.
[16] I. Horsfall, P.D. Prosser, C.H. Watson, S.M. Champion, An assessment of human performance in stabbing, Forensic Science International 102 (1999) 79–89.
[17] I. Horsfall, C.H. Watson, S.M. Champion, P.D. Prosser, T. Ringrose, The effect of blade handle shape on stabbing performance, Applied Ergonomics 36 (2005) 505–511.
[18] S.E. Kemp, D.J. Carr, J. Kieser, B.E. Niven, M.C. Taylor, Forensic evidence in apparel fabrics due to stab events, Forensic Science International 191 (2009) 86–96.
[19] P.T. O'Callaghan, M.D. Jones, D.S. James, S. Leadbeatter, C.A. Holt, L.D.M. Nokes, Dynamics of stab wounds: force required for penetration of various cadaveric human tissues, Forensic Science International 104 (1999) 173–178.
[20] P.N. Brett, T.J. Parker, A.J. Harrison, T.A. Thomas, A. Carr, Simulation of resistance forces on surgical sutures, Proceedings of the Institute of Mechanical Engineers, Part H: Journal of Engineering in Medicine 211 (1997) 335–347.

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[21] M.D. Gilchrist, S. Keenan, M. Curtis, M. Cassidy, G. Bryne, M. Destrade, Measuring knife stab penetration into skin simulant using a novel biaxial tension device, Forensic Science International 177 (2008) 52–65.
[22] S.E. Gore, R.M. Laing, C.A. Wilson, D.J. Carr, B.E. Niven, Standardizing a pre-treatment cleaning procedure and effects of application on apparel fabrics, Textile Research Journal 76 (2006) 455–464.
[23] N. Johnson, Physical damage to textiles, in: J. Vernon, D. Berwick (Eds.), Police Technology: Asia Pacific Police Technology Conference, Australian Institute of Criminology, Canberra, 1991.
[24] N. Johnson, A. Stacy, Forensic textiles: the morphology of stabbed fabrics, Australasian Textiles 10 (1991) 32–33.
[25] T. Karlsson, Homicidal and suicidal sharp force fatalities in Stockholm, Sweden, Forensic Science International 93 (1998) 21–32.
[26] International Organization for Standardization, ISO 6330/A1:2009 Textiles – Domestic Washing and Drying Procedures for Textile Testing, International Organization for Standardization, Geneva, Switzerland, 2009.
[27] British Standards Institution, BS EN 12751: 1999 Textiles – Sampling of Fibres, Yarns and Fabrics for Testing, British Standards Institution, London, UK, 1991.
[28] British Standards Institution, BS EN 12127: 1998 Textiles Fabrics Determination of Mass per Unit Area Using Small Samples, British Standards Institution, London, UK, 1998.
[29] International Organization for Standardization, ISO 5084: 1996 Textiles – Determination of Thickness of Textiles and Textile Products, International Organization for Standardization, Geneva, Switzerland, 1996.

Please cite this article in press as: D.J. Carr, A. Wainwright, Variability of simulants used in recreating stab events, Forensic Sci. Int. (2011), doi:10.1016/j.forsciint.2011.01.032