# On a Knife Edge: A preliminary investigation of clothing damage using rounded-tip knives

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**Highlights**

- Significant differences between the blade design and clothing damage.
- A correlation between the rounded tip knife  and no resulting clothing damage.
- Rounded-end tip knives are a safer alternative to conventional knife blade designs.

**Abstract**

Bladed weapons are frequently encountered in violent crime offences including street based and armed robberies, murder, sexual assaults and terrorism. A study was conducted involving four frequently encountered clothing fabrics: t-shirt (knitted cotton), denim jeans (twill woven cotton), long sleeved top (knitted synthetic blend), and skirt (non-woven faux leather) and five knives to investigate any damage resulting from a downward stabbing motion, with 300 stabs in total. Any resultant penetrating severance damage was then photographed, measured and analysed. Statistical analysis revealed significant differences between the stab hole size and shape, as a consequence of the design of a bladed weapon (in particular, the tip shape) that caused it. There is a notable correlation between the Assure knife (rounded tip) and no resulting severance damage, as the fabric surfaces were not breached with this knife. This suggests a clear alternative to pointed tip knife blades. These findings will be of interest to investigators of knife crime offences, crime-reduction units, knife manufacturers and practitioners, who share the goal of identifying a safer alternative to conventional knife blade design.

**Key Words**

Rounded-End Knives; Pointed Tip; Knife Crime; Stab holes; Fabric Penetration. Severance Damage; Sharp Force Trauma.

## 1. Introduction

There were 44,771 offences (excluding Greater Manchester Police) involving a knife or sharp instrument (including screwdrivers, broken bottles, scissors) recorded by UK (England and Wales) police forces in the year ending September 2019 [1]. This represents a 7% annual increase over the previous year and an overall increase of 46% since comparable recording commenced in the year ending March 2011; it is the highest on record. Many of these offences occur in urban areas; however, rural communities are also significantly impacted. These offences are not only open space/street assaults (serious street-based violence) involving knife carriage often reported in the media but also domestic incidences within residential properties, as well as robberies and even sexual assaults. Despite the introduction of the Offensive Weapons Act [2] to restrict the supply, possession and receipt of bladed implements, domestic kitchen knives are prevalent in violent offences [3–5]. There is a correlation between increased offence numbers and the attendance of injured persons at hospitals for medical treatment. The National Health Service (NHS) recorded 5,149 finished consultant episodes (FCE) in 2018/19 due to assault by a sharp object, which is a 2% increase on the previous year and 41% higher than 2014/15 [6]. The British Medical Association (BMA) declared that knife crime should have a public health response across the UK [7]. This is consistent with the 50% decline in sharp force injuries within Scotland between 2008 and 2013 as a result of a multi-agency response and public health initiatives to reduce societal inequalities [8].

In this work, the forensic examination of textile damage is undertaken to determine the weapon type involved and circumstances of the incident. The analysis includes morphological terminology with consideration of theoretical principles such as garment construction, impacts of laundering and environmental exposure [9]. However, this is a subjective discipline developed with the practitioner's experience, opinion and professional judgement [10]. A number of studies have investigated textile damage. Taupin [11] discussed variabilities within fabric types in determination of weapon geometry. Monahan and Harding [12] were able to determine age of clothing damage, whilst distinguishing cuts, tears, slashes and stabs. The potential transfer of fibre evidence from the clothing garment to the weapon is another vital forensic opportunity [13,14]. Previous research studies have utilised a range of fabrics and knives, in order to simulate sharp force trauma encountered in casework situations. One study [15] utilised four knives and seven fabrics during stabbing experiments in which each fabric was tested in two ways (loose or stretched) on animal skin, to determine any correlation between length of skin wounds and clothing damage. It concluded that the garment fabric has a direct effect on corresponding marks on the skin and fabric, with natural fibres producing the greatest variability. Another study [16] used a variety of simulants for their research including pork, gelatine and expanded polystyrene with a Tuftane 'skin', where pork was shown to be an unreliable simulant medium as opposed to the expanded polystyrene, which demonstrated the lowest variability in severance data. Gilchrist *et al* [17] used polyurethane, ballistic soap and compliant foam to replicate the interaction of skin, subcutaneous fat and cartilage, which showed disparities in resistance (tension). The shape of knife handles in relation to stabbing performance was also investigated, where the use of a finger guard or hilt was shown to increase the mean energy directed at the target surface [18]. Stabbing testing [15,19] has been used to manually replicate stabbing forces and directionality, whilst an automated robotic machine [20] was able to demonstrate sixty stabbing positions. The kinematics of stabbing movements can also aid in reconstruction of the event [21]. Other studies [22,23] have investigated sharpness of kitchen knives in relation to stabbing incidents, where the radius of the blunt edge at the tip is vital in controlling the penetration ability of a knife, and velocity of biomechanics.

Previously, the judiciary, NHS trauma surgeons, forensic engineers and police investigators have suggested that the knife tip directly determines any resulting penetrative stabbing injury. O'Callaghan *et al* [24] confirmed that once skin penetration has occurred, no further force is required to penetrate other underlying body tissues. However, previous research published by Jones *et al* [25] concluded that despite skin providing a primary level of resistance, a secondary level exists in deeper muscle layers.

Sloan *et al* (2018) concluded interaction of multiple variables (including knife blade profile) was responsible for textile damage, whereas Knight [26] concluded that in relation to stab cuts, ease of penetration was dependent upon the cross-sectional area of the blade tip. There are three fundamental considerations with stab cuts and knives: penetration, the blade and secondary cuts [10]. Costello and Lawton [27] observed that stab cut length dimensions did not correlate with blade weapon width. Such a disparity could well have been due to differences in the fabric surfaces used. Other studies have [28,29] discussed the shape of blades and long pointed blades were found to be the fundamental cause of stabbing injuries. They also reported that despite the chest and abdomen, as being commonly injured areas, peripheral locations (legs, arms and buttocks) are also targeted by assailants to result in long term health issues (stomas).

In broad terms, this work seeks to establish basic aspects of the relationship between knife tip design and clothing damage resulting from the knife being used in a stabbing action. The study is motivated by the recent commercial availability of round tip design knives, notionally associated with the potential for reduced stabbing injury. Specific objectives are the effects of (i) round-ended (*cf.* pointed) knife tip shape and (ii) fabric type (exemplified by some commonly used examples). Correlating the outcomes of these two objectives, the subsequent aim is to identify scenarios (of knife and fabric types) associated with minor and major injuries. The intention is that the outcomes of the study will lead to recommendations for crime reduction and criminal investigation in the societally significant field of knife crime.

## 2. Materials and Methodology

### *2.1 Knives*

Five different kitchen knives, obtained from various retailers, were used in this study. The dimensions of each knife were recorded, which included: total length of the knife, blade length, blade width, blade thickness, knife weight and the blade tip angle. The blade tip angle (relating to the point of the tip) was measured using a protractor, this was the angle between the blunt edge (spine) and the cutting edge. This was achieved by lying the knife flat on to a bench surface (in profile view as in Figure 1) and the blade tip being viewed under a stereo microscope, influenced by the methodology and terminology used in other studies [22,30,31]. Additionally, the blunt top edge (spine) of each blade was measured with a protractor, to determine if there was any bend in the blade from the handle, which could have occurred as a result of previous damage in transit or storage, which may have then impacted the experimental results. All top edges (spines) were measured at $0^{o}$, therefore, each knife was deemed appropriate to be utilised in the study [22,30,31]. Figure 1 shows the different types of knives used and Table 1 summarises the details and dimensions of each knife. For the duration of the study, the knives were each assigned an identifier code and for safety purposes were stored in plastic weapon tubes.


(a) (b) (c) (d) (e)

**Figure 1 – The five knives used in the study: (a) Taylor's; (b) Viners Assure; (c) Prestige; (d) John Lewis and (e) Sabatier and Judge.**

**Table 1: Details and dimensions of knives used in the study.**

| | **Knife A** | **Knife B** | **Knife C** | **Knife D** | **Knife E** |
|---|---|---|---|---|---|
| Retailer | Taylor's | Viners Assure | Prestige | John Lewis | Sabatier and Judge |
| Description | black plastic handled knife with straight edged blade and 'R-shaped' tip | black handled knife with black coloured straight edged blade and rounded end | black plastic handled knife with straight edged blade and asymmetric tapered tip also known as a 'sheepsfoot' | silver coloured metal knife with straight edged blade and pointed tip | black plastic handled knife with serrated edged blade and pointed tip |
| Total Knife Length (mm) | 245 | 214 | 196 | 215 | 220 |
| Blade Length (mm) | 120 | 105 | 91 | 105 | 112 |
| Blade Width (mm) | 30 | 22 | 19 | 24 | 20 |
| Blade Thickness (mm) | 1 | 1 | 1.5 | 2 | 1 |
| Blade Tip (Plane/Plan) Angle ($^o$) | 70 | 110 | 80 | 22 | 21 |
| Knife Weight (g) | 37 | 46 | 54 | 87 | 45 |

*2.2 Clothing Fabrics*

The clothing garments were sourced from a charity donation shop as it was intended for the garments to have been previously used (laundered and worn). This is more consistent with the clothing exhibits encountered in forensic laboratory examinations, rather than garments with minimal previous wear. Clothing fabrics used within this investigation replicated those utilised in a previous study involving arrowheads [32]. The four garments selected for this research were a combination of upper clothing (t-shirt and long-sleeved top) and lower clothing (jeans and skirt), which is consistent with bodily areas targeted in stabbing incidents as reported by Hern *et al* [28] and Wilkinson [29]. A breakdown of the garments and their properties are provided in Table 2.

Table 2: Garment characteristics for each of the four chosen clothing items

| | Garment type | Manufacturer | Garment structure | Garment composition | |
|---|---|---|---|---|---|
| | | | | Major (approx. %) | Minor (approx. %) |
| Fabric 1 (Knitted Cotton) | White T-shirt | Stedman | Weft knitted | Cotton (100) | n/a |
| Fabric 2 (Woven Cotton) | Blue Denim jeans | Burton Menswear | Twill weave | Cotton (100) | n/a |
| Fabric 3 (Knitted Synthetic Blend) | Grey Long sleeved top | Marks & Spencer | Weft knitted | Polyester (60) | Cotton (40) |
| Fabric 4 (Non-Woven Faux Leather) | Black Faux leather skirt | Oasis Clothing | Non-woven | Outer: Polyurethane (100)<br>Inner: Polyester (50) | Outer: n/a<br>Inner: Viscose (50) |

*2.3 Garment and fibre characterisation*

The garment structure (knitted, woven, non-woven) was characterised using brightfield microscopy (Leica S9i, magnification range 10-50x). A sample of fibres was then plucked from the surface and mounted on to a glass slide with phytohistol and covered with a glass coverslip. Brightfield microscopy (Olympus CX23, magnification 100-400x) was again used to determine the generic type(s) of fibres used in the composition of the garments and their approximate percentage weightings. Generic fibre types were classified as cotton, viscose or synthetic. Infrared absorption spectra were acquired on a FTIR spectrometer Spotlight 150i (Perkin Elmer) for generic fibre types identified as viscose and 'synthetic'. Measurements taken in the transmission mode across a spectral region spanning 4000 to 600 $cm^{-1}$, with a resolution of 4 $cm^{-1}$. The fibre sample was flattened and suspended across a slit to allow a measurement to be taken in transmission mode.

*2.4 Garment sampling*

Five separate square shaped sections, measuring approximately 300mm x 300mm, were cut from each of the four clothing garments (one for every knife being tested, a total of 20 fabric sections). Additionally, a grid (approximately 150mm x 200mm) was marked on each of these, resulting in 15 squares (figure 2). The fabric sections were stored in ambient environmental conditions.

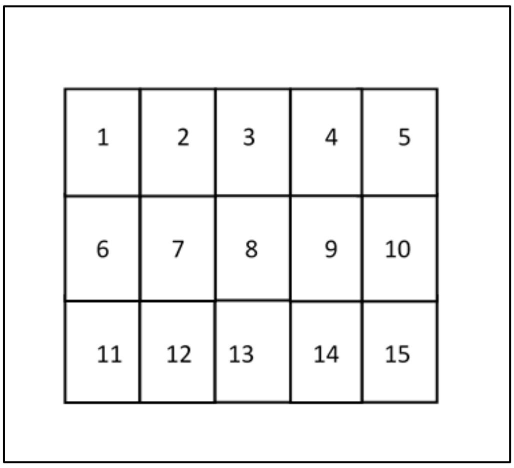



**Figure 2 – An example of a grid prepared on fabric ready for stabbing**

*2.5 Experimental Set-up*

A Black and Decker workmate bench was erected in an upright position to be 1m from the floor. Two sections of pine wood measuring approximately 2.5 cm x 10 cm x 30 cm were fixed at either side of the work bench surface with screws, ensuring a visible gap was present. The fabric squares were individually placed onto the two base wood sections before two further pieces of wood were placed onto the fabric and screwed in place. The workbench cog was then turned to open the work bench fully, providing a taut fabric surface. This was to minimise any fabric movement or gathering, whilst ensuring a single layer fabric surface for the experiments. A vertical ruler scale was positioned on the bench surface near to the fabric surface. The experimental set-up ensured that the grid tension was as consistent as possible, although this was not measured. The wooden blocks secured the outer fabric edge only, this then ensured that there was a substantial border space surrounding the marked fabric grid. Therefore, the wooden block positioning, minimised any influence on any damage created. It is acknowledged that tension may be altered after repeated damage to a surface, however, it was deemed that the tension was constant throughout, as each knife impact targeted a distinct grid location. Additionally, the results observed within each grid location were visually consistent.

*2.6 Stabbing procedure*

The knife handle was held in a gripped position by the right-handed researcher with their thumb towards the end of the handle (figure 3). The researcher wore Warrior WC+C5 anti-cut safety gloves, which adhered to EN388:2003. The knife tip was approximately 30 cm from the fabric surface prior to each stabbing movement. An attempt was made to keep the force and speed of the stabbing motion as consistent as possible. A 90$^{o}$ angle (perpendicular to the surface) continuous downward stabbing motion (approximately 2 seconds in duration) was used before the knife tip made contact with the fabric surface for approximately 1 second in a designated marked square on the fabric grid, before the knife returned to its original starting position (in a vertical movement lasting approximately 2 seconds). Throughout the experiments, the technical face of the fabric was targeted and impacted. Each fabric surface had 15 different damage attempts caused by each knife type (see figure 2). Thus, 75 test areas for each of the 4 fabric types (caused by 5 different knives) generated a total of 300 test areas. No backing was used under the fabric (if a knife penetrated the fabric it entered the void opening of the workbench surface), this was to ensure no potential resistance from a simulant which could impact any resulting damage observed.

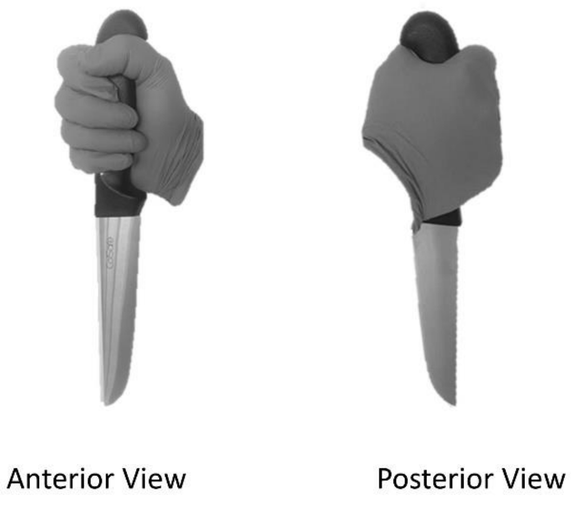



**Figure 3 – Anterior and posterior views of the knife handle grip during stabbing.**

It was important to consider the positioning of threads and rows within each garment, as the direction of knife impact could potentially result in varied damage. To ensure consistency, every fabric square (from each of the four substrates) was orientated in the same position for the stabbing procedure. A further study will investigate different orientations of the substrates. No simulants were utilised in this study as this preliminary investigation was initially focussed on the interaction of the knife tip impacting with the target surface. However, simulants will be incorporated in the scope for a future extension study. Additionally, the researchers acknowledge the importance of the knife withdrawal mechanism, however, this was outside the scope of this particular research study.

*2.7 General imaging and data analysis*

General photography was performed using a Nikon D3500 SLR camera and a 18-55 mm lens. Any resulting fabric damage was also imaged with the DSLR camera utilised with an 'L' shaped scale ruler (Sirchie PPS600). Severance length measurements of any visible clothing damage were recorded. From the data, the mean, standard deviation, standard error, and coefficient of variation were calculated. Additionally, analysis of variation was conducted to compare means within the data to assess for significance. All statistical calculations were conducted using Microsoft Excel Office 365.

*2.8 Scanning Electron Microscopy (SEM)*

In order to examine fabric damage in greater detail, SEM imaging was conducted (EVO LS15 SEM, manufactured by Carl Zeiss, Cambridge, UK). Individual areas of damage were excised from each fabric type (approximately 20 mm x 20 mm in size). Each fabric section was then mounted onto the adhesive surface of a black carbon tab which was then adhered to a circular aluminium SEM 25 mm stub (Agar Scientific, Stansted, UK). Each stub then underwent a gold mineral coating process using the sputter coater Q150RS machine (Quorum Technologies, Sussex, UK) whereby a 15 nm layer of gold was applied. All stubs were then analysed under high vacuum with a beam accelerating voltage of 10 kV, a probe current of 100 pA and images captured at various magnifications.

## 3. Results and Discussion

In order to maximise the clarity of the comparisons made, the observations of the effects of fabric type and knife are separated. Firstly, the data grouped according to fabric (extracting the effect of blade design), then the data grouped according to blade design (extracting the effect of fabric type). Subsequent discussion focuses on the cross-correlation of the two variables.

### *3.1 Garment Fabrics*

Figure 4 presents a visual summary of the knife impact results on the four garment fabrics, with table 3 providing numerical data for average damage length.

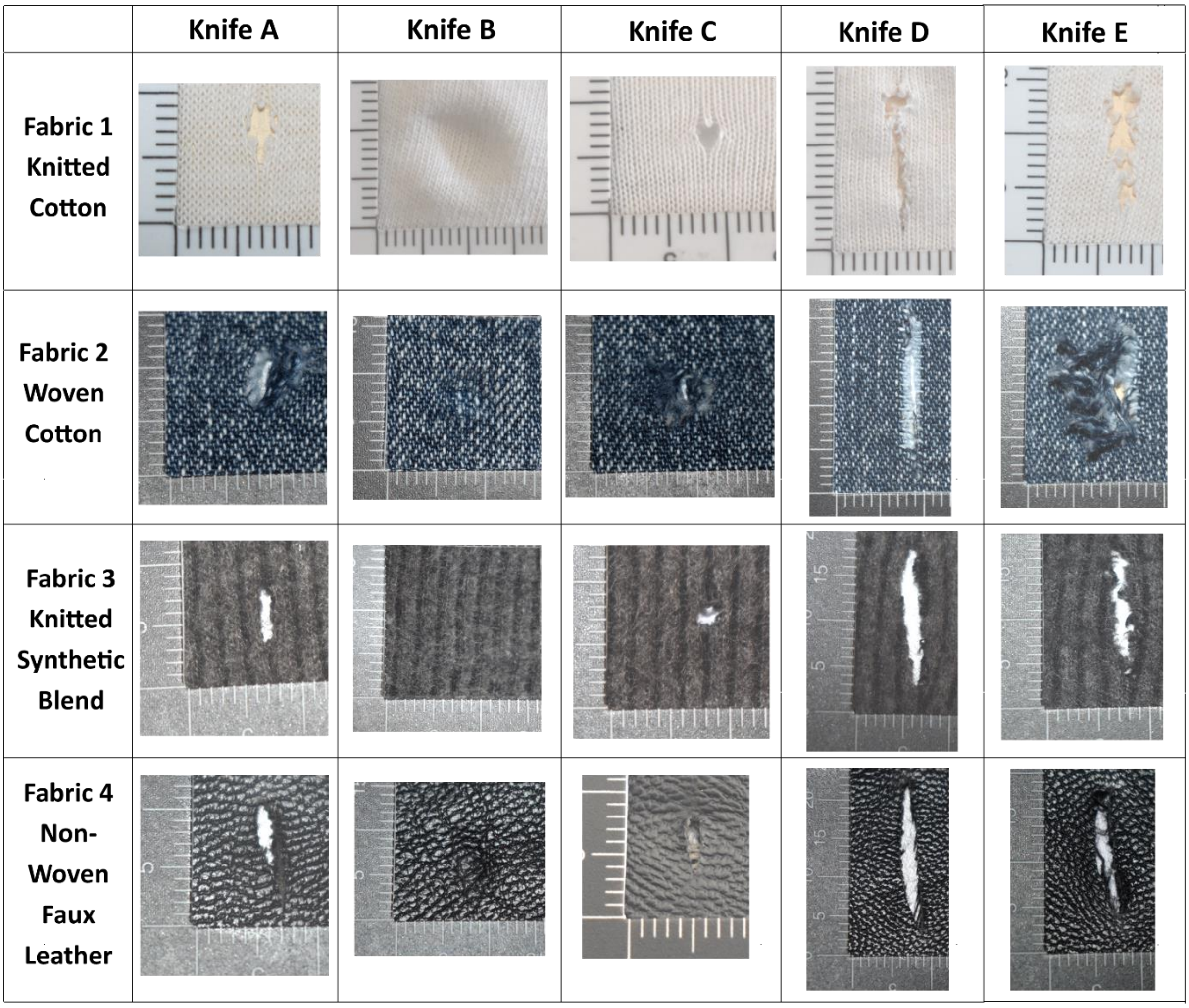



**Figure 4 –** Example of fabric damage with the various knives used in the study photographed using a DSLR camera with scale ruler (as shown with each image). Please note, the scale ruler (as shown) is in 1mm increments.

**Table 3 – Average damage length (mm) for each knife and fabric type.**

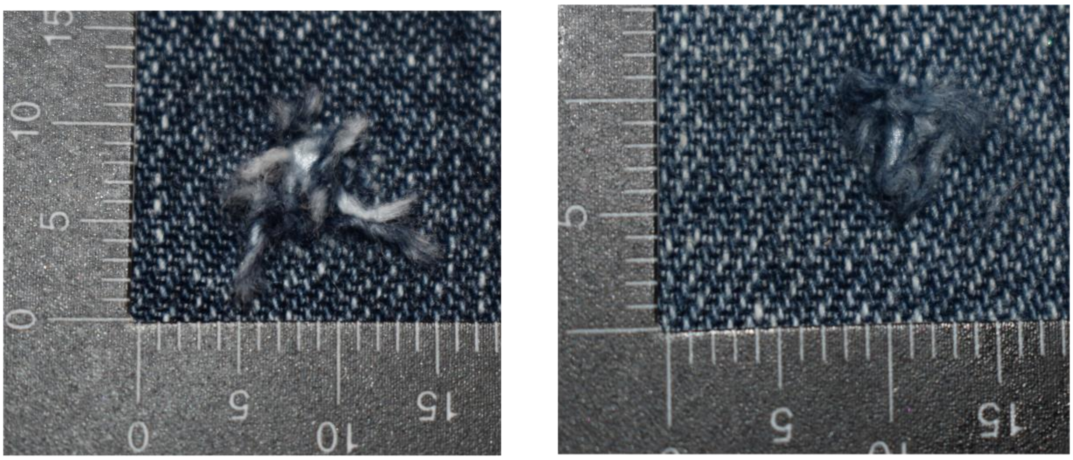
| | Knife A | Knife B | Knife C | Knife D | Knife E |
|---|---|---|---|---|---|
| **Fabric 1** | 4.8 ±1.5 | 0 | 2.6 ±0.5 | 14.1 ±1.0 | 13.2 ±1.9 |
| **Fabric 2** | 3.7 ±1.3 | 0 | 1.5 ±0.6 | 15.7 ±2.6 | 14.0 ±1.5 |
| **Fabric 3** | 6.1 ±2.3 | 0 | 2.1 ±0.6 | 14.9 ±1.6 | 12.7 ±1.9 |
| **Fabric 4** | 5.1 ±0.7 | 0 | 3.0 ±1.3 | 19.7 ±2.5 | 15.0 ±2.2 |

#### *3.1.1. Fabric 1: White T-shirt (Knitted Cotton)*

The resulting penetrating damage to this fabric is visibly different, depending upon the corresponding knife. Knife A produced openings with an average damage length of 4.8 mm. However, knife B did not penetrate this fabric at all. A depression within the surface (as visible in the image within figure 4) identifies the impact site. This impact surface depression is consistent with findings reported in another study [32] involving arrowheads. The knitted cotton fabric did allow for flexibility and stretching, which is an important consideration when analysing the damage. However, the experimental set-up ensured a taut, not stretched, substrate. Knife C resulted in a noticeably smaller opening with an average damage length of 2.6 mm. However, the two, pointed tipped knives; D and E, produced distinctive damage areas. Knife D produced a narrow opening with an apparent 'T' shape at one end and a tapered end at the other, which enabled the identification of the spine edge (T shape) from the cutting edge (tapered end). Knife D produced slightly greater average damage length (14.1 mm) than knife E (13.2 mm). The damage caused by knife E had visible jagged edges which correlated with the serrated blade.

#### *3.1.2. Fabric 2: Blue Jeans (Woven Cotton)*

Damage visible on the woven cotton fabric could be differentiated by the knives responsible. Knife A produced narrow openings with an average damage length of 3.7 mm. Knife B created a slight depression in the woven cotton surface, which was consistent with the knitted cotton, however, the surface remained intact and no penetration occurred. In contrast, knife C produced interesting areas of damage in that they resembled small circular puncture holes and frayed edges, with an average damage length of 1.5 mm. These findings are significant for practitioners as the observed damage is not what is typically associated with knives (from the researcher's practitioner experience). Such openings could be representative of penetration damage, resulting from screwdrivers, as weapons. To investigate this observation, two screwdrivers (one flat head ended, one cross head 'Philips' ended) were utilised, in the experimental set-up, to impact the woven cotton surface. Images of the resulting damage clearly show two round shaped puncture holes (figure 5). The edges of this screwdriver damage are uneven, with protruding fibres. There are similar in appearance to the damage produced by knife C. These findings are consistent with those reported in other studies [14,33,34]. Knife D produced straight edged narrow elongated openings with an average damage length of 15.7 mm. In contrast, knife E resulted in stab holes with irregular jagged edges; averaging 14 mm damage length, with protruding fibres. The woven cotton fabric had a pronounced ridged texture to the technical face, which would most likely influence any resulting penetrating damage, in creating resistance. A further consideration is that this substrate was the only woven fabric within the study, therefore, this could be a further explanation for the resulting damage, which is unlike that produced by the other knives.



(a) (b)

**Figure 5 - Image showing visible puncture damage to the denim surface from different screwdrivers (a) flat head and (b) cross head**

*3.1.3. Fabric 3: Grey Long-Sleeved Top (Knitted Synthetic Blend)*

The knitted synthetic blend had a ribbed texture with an ability to stretch. However, the experimental set-up ensured that this substrate was taut. It must be acknowledged that this fabric was orientated to ensure that the ribbed texture direction was consistently in a vertical position throughout the stabbing experiments. An alternative alignment could have impacted the visual appearance of any resulting damage produced and will be explored in other experiments. Knife A produced narrow damage with 6.1 mm (+/-2.3) average length. Whereas knife B did not penetrate the fabric at all, and unlike the other fabrics, there was no depression indicating the impact area. This is most likely, as a result, of the flexibility within the fabric. Knife C created small puncture holes (similar in appearance to those created on the knitted cotton fabric) with an average damage length of 2.1 mm. Knife D resulted in oval shaped damage blunt at one end consistent with the knife spine and one tapered end that aligned to the cutting edge, with 14.9 mm average damage length. Knife E produced uneven shaped openings with average damage lengths of 12.7 mm, the jagged edges consistent with a serrated knife.

*3.1.4. Fabric 4: Black Skirt (Non-Woven Faux Leather)*

Knife A penetrated the non-woven faux leather surface causing oval shaped openings with 5.1 mm average damage length. Knife B failed to penetrate this fabric on all attempts, however, the impact site was visible with a round depression, which can be visualised in the image (figure 4). Knife C created the smallest damage of all the knives, with puncture holes averaging 3mm in length. Knife D produced tapered elongated openings which were the largest of the entire study averaging 19.7 mm in length. Knife E resulted in damage with uneven frayed edges averaging 15 mm in length.

*3.2 Knives*

Figure 6 is a graphical representation of the average damage lengths on the four garment fabrics involving the five knives in this study. The inclusion of knives D and E in our study is justified as these are conventional kitchen knives encountered in casework situations. The resultant damage from knives D and E, is a useful comparative tool for the other three knives.

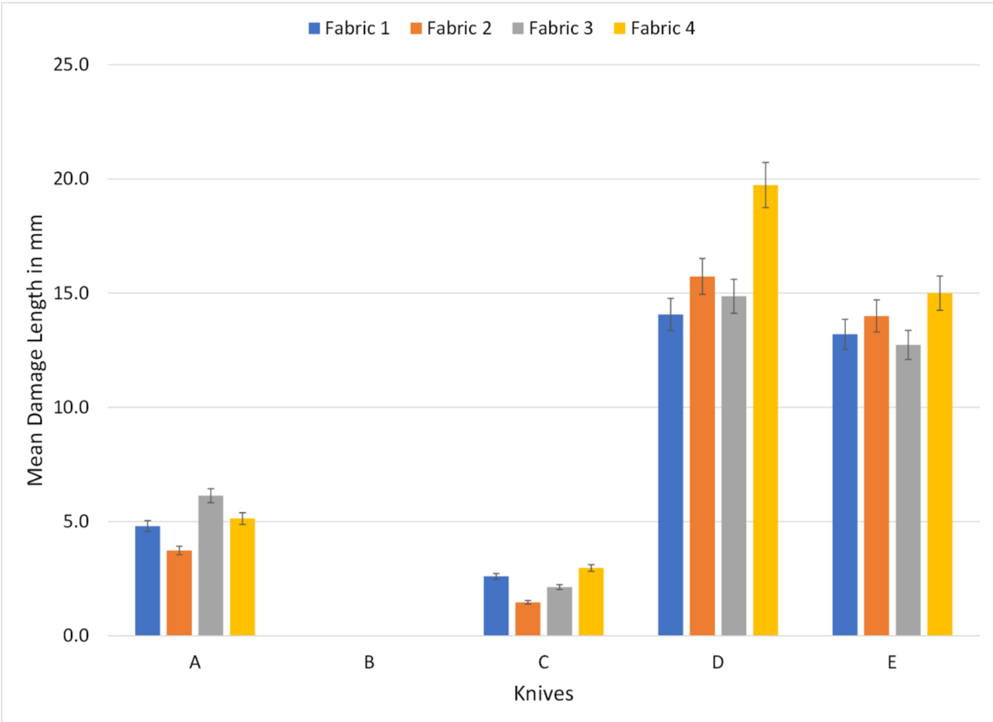



**Figure 6 – Average damage length (mm) on clothing fabrics across the knives used in the study.**

*3.2.1 Knife A*

This knife had a distinctive 'R-shaped' end comprising a curve from the blade spine protruding over a pointed blade and cutting edge. This knife successfully penetrated each garment fabric. It produced the greatest damage on the knitted synthetic blend, followed by the non-woven faux leather, knitted cotton, and the least damage to the woven cotton. It must be acknowledged that the average damage lengths were similar and consistent in morphology, with the average damage lengths varying by 2.4 mm from the knitted synthetic blend to the woven cotton. Despite this finding, it is evident that this knife has penetrated the fabric, with the possibility of breaching the skin, resulting in potential injuries.

*3.2.2 Knife B*

This knife had a blade with a rounded end. On all stab tests, knife B did not penetrate any of the four garments (n=60 stab tests), thus no severance damage was produced. On three garments (knitted cotton, woven cotton, non-woven faux leather), it was evident where the impact site was as a depression had been formed in the fabric. However, the fabric surfaces remained intact. This is a highly significant observation with regards to damage examinations, in which knives are the alleged weapon.

### *3.2.3 Knife C*

This knife had a distinctive 'sheepsfoot' (asymmetric) blade tip. However, the blade tip was pointed and thus penetrated all four garments. There was 1.5 mm difference between the average damage length produced on the non-woven faux leather than the puncture marks on the woven cotton. The resulting damage from knife C was the lowest produced by the four penetrating knives, however, as with knife A, once the garment fabric is breached then it would no longer act as a barrier for the skin, potentially resulting in injury.

### *3.2.4 Knife D*

This knife had a straight edged blade with pointed tip. It resulted in the longest damage out of the five knives utilised within this study, with the non-woven faux leather resulting in the greatest average damage length, followed by the woven cotton, knitted synthetic blend and knitted cotton. There was a 5.6 mm difference between the average damage length of the non-woven faux leather than the knitted cotton, possibly as a result, of the weave structure and stretch within the knitted cotton hindering the penetration of the blade through the surface. The morphology of the damage, displaying straight cut edges to the clothing fibres, was consistent with such a blade, as reported elsewhere [34].

### *3.2.5 Knife E*

This knife had a serrated blade with pointed tip. Similar, to knife D, knife E penetrated all four garments, resulting in the greatest damage to the non-woven faux leather followed by the woven cotton. However, unlike knife D, knife E produced greater severance damage to the knitted cotton than the knitted synthetic blend. This was possibly due to the ribbed texture of the latter creating resistance for the serrated teeth of the blade as it was attempting to penetrate the fabric. It is acknowledged that there was a 2.3 mm difference between the average damage length of the non-woven faux leather as compared to the knitted synthetic blend. However, knife E surpassed three knives in the study for severance damage length. The morphology of all damage is consistent with a serrated knife in producing irregular jagged edged openings, with frayed fibre endings, as observed in other studies [20].

## *3.3 SEM Imaging*

SEM was selected to analyse the fabric samples, as this technique can image at high resolution and offers a greater depth of field than optical microscopy. This enabled the fibre ends to be analysed at a high magnification to observe any damage to them. Figure 7 demonstrates SEM images of fabric damage on knitted cotton (T-shirt fabric) by the different knives at a low and high magnification. The penetration and damage to the cotton fibres differs for each of the knives. As discussed previously, four knives (A, C, D, and E) resulted in penetrating damage, whilst knife B resulted in no penetrating severance damage, therefore it can be observed that the knitted cotton surface is intact following a 'stabbing' impact from knife B.

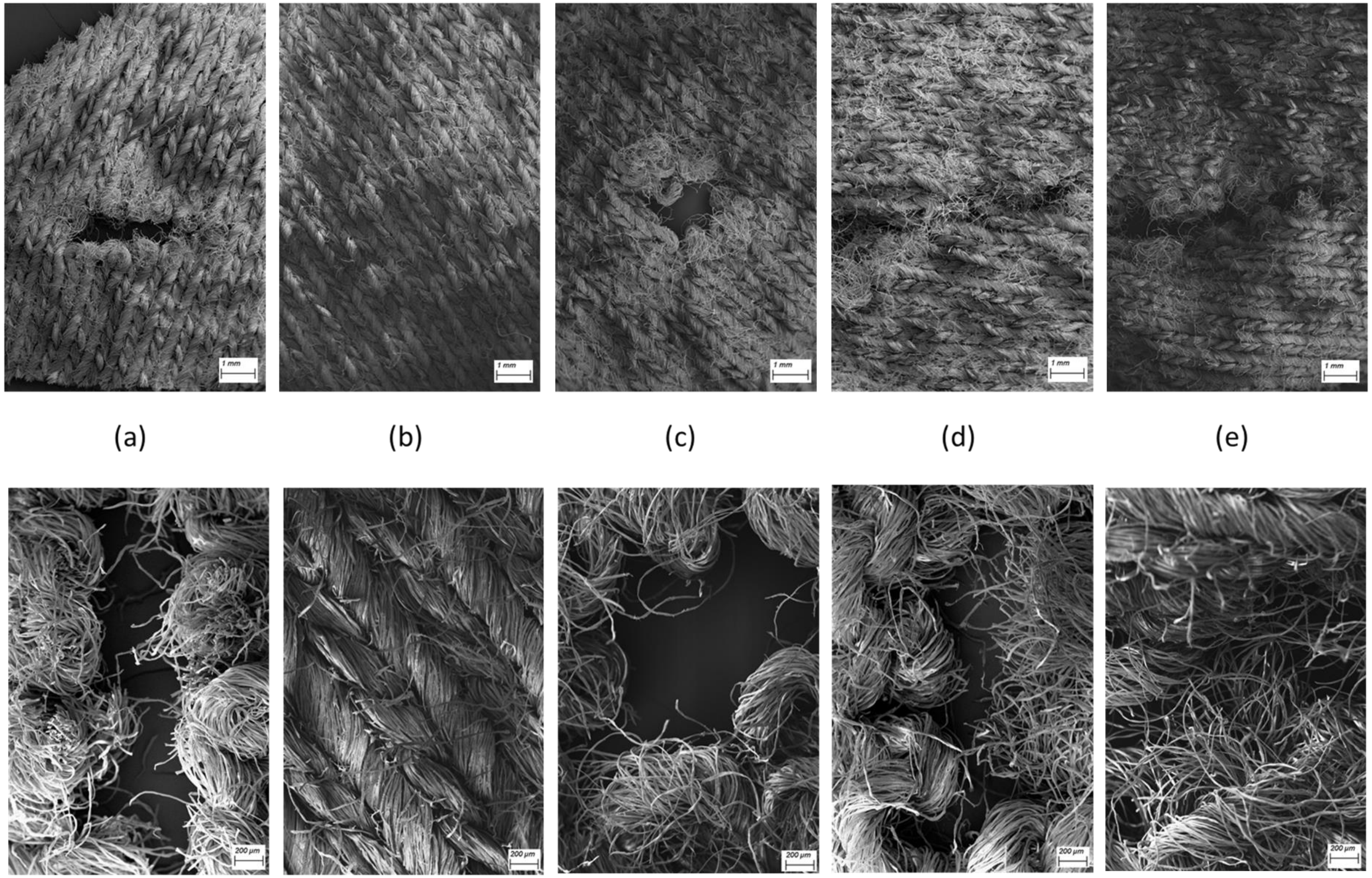



**Figure 7 – Knitted Cotton damage by different knives as observed by SEM at two magnifications: (a) Knife A (b) Knife B (c) Knife C (d) Knife D and (e) Knife E**

*3.5 Statistical Analysis*

The results (Figure 6 and table 3) in this study revealed that the means of the average damage length measurements caused by knives with varied blade tip shapes are visibly different. The data generated from the study underwent ANOVA analysis to statistically assess any difference between the mean severance damage. For this study, the null hypothesis relating to knife design is that all knives produce the same mean severance damage. The alternative hypothesis is that the mean severance damage length varies with knife design. For all knives, the F test was greater than the F critical value, with 0.05 as the alpha level. The ANOVA for knife A ($F$ (3,56) = $5.924$, $p= 0.00139$) with 2.769 as the F crit value, therefore, the null hypothesis must be rejected.

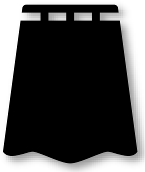
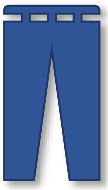
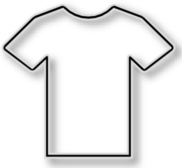
Analogously, ANOVA was also used to determine whether there were significant differences between the substrate surfaces. In this instance, the null hypothesis relating was that all fabrics undergo the same mean severance damage. The alternative hypothesis was that the mean severance damage length varies with fabric. For all garment fabrics, the F test was greater than the F critical value, with 0.05 as the alpha level. The T-shirt ANOVA ($F$ (4,70) = 426.93, $p= 2.3582\times10^{-48}$) with 2.502 as the F crit value, therefore, the null hypothesis must be rejected. Therefore, the ANOVA statistical analysis has demonstrated to a 95% level of significance that both the blade tip shape of knives and the fabric upon which they impact does influence the resulting severance damage. The former is highly significant for crime reduction and the latter for crime investigation.

Ultimately, the ability of a fabric to impede a stabbing action, could potentially offer protection in the event of a knife incident. By combining this information with the effect of knife tip shape, a “hazard map” of knife and clothing combinations was constructed that ranges from very limited (green) to very significant (red) damage (Table 4). Speculatively, this may be considered as a map of likely degree of injury for a given combination if the garment were to be breached. It is evident that Knife B is deemed the safest option, as it resulted in no severance damage for any of the four clothing items.

*3.6 Limitations and Opportunities*

In this section the findings of this preliminary study are summarised, with the additional purpose of setting out the avenues for future research that it has highlighted. In an attempt to explore some aspects of the problem in sufficient depth to extract useful conclusions, it has been necessary to focus on a small number of parameters. This study engaged only one “assailant”, making “attacks” of only one type and strength. In practice, one may encounter a range of different stabbing actions, even within a single incident. While a slashing action was not considered, this exclusion was based on the expectation that the variation of knife tip design (the focus of the first objective) is more likely to influence the consequences of a stabbing action (short, deep incision) than those of a slashing action (long, shallower incision). Nonetheless, this might be explored, particularly in the context of knife blade (*cf.* knife tip) design. Additionally, the effect of different levels of force / velocity might be considered, particularly if one were to quantify this.

**Table 4 – Hazard Map of Knife Tip Shape and Garment Substrate**

| | Knife D  | Knife E  | Knife A  | Knife C  | Knife B  |
|---|---|---|---|---|---|
| Fabric 4  | | | | | |
| Fabric 2  | | | | | |
| Fabric 1  | | | | | |
| Fabric 3  | | | | | |

This study has deliberately chosen (in terms of the second objective) to focus on the fabric, stationary and in isolation. This leaves the effects of victim motion (anisotropic material stress) and underlying support (skin and tissue) unexplored at this stage. However, although no skin simulants were used under the fabrics to represent skin or body tissue, examinations of fabric damage are a valid undertaking within the forensic laboratory. Finally, knife sharpness and knife withdrawal mechanisms are outside the scope of this study. The fabric sections in this study were secured in place to be a taut substrate surface. However, garments may be loosely worn on the person and this is a future consideration. Additionally, variabilities within the fabrics themselves, must be considered, such as stretch, weave, composition, and the inability to determine the number of times each garment had been worn and laundered, prior to the experiments. These factors could have influenced the resulting damage caused by the knives. This study has considered single layered fabrics, whereas an individual may be wearing multiple garments or layers at once. However, this study is deemed to be consistent with garments encountered in casework situations.

The above list of unexplored parameters should not be seen as a shortcoming. Rather, it points to the development in this preliminary work of a methodology suitable for wider application to the exploration of these parameters. Focus on knife tip shape and representative fabric types has allowed useful conclusions to be drawn for some operationally relevant scenarios. Furthermore, the ability to make replicate measurements permits estimation of the variability of stabbing action damage: this allows reasonable evaluation of the "envelope of likely responses", such that one could avoid undue levels of assertion (i.e. over-interpretation).

## 4. Conclusion

This report characterises some basic aspects of the relationship between knife tip design and clothing damage resulting from the knife being used in a penetrating stabbing action. This has been explored for five knife blade designs (including one novel round tip shape) and four common clothing fabrics (knitted cotton, woven cotton denim, knitted synthetic blend, non-woven faux leather). In each case the "attack" was a single type of downward stabbing action on taut, but unsupported (no underlying skin simulant), fabric. However, this has resulted in a marked spectrum of damage patterns. One knife produced penetrating damage similar in appearance to screwdriver puncture holes. Significantly, the round tip knife blade resulted in no significant damage to any of the fabrics. This suggests an opportunity for crime reduction – a knife of culinary utility without the possibility of accidental injury, and with little or no value in violent crime.

Notwithstanding the above list of hitherto unexplored parameters, the study was able to draw some important conclusions. Significantly, through investigation of the primary aspects of knife tip shape and fabric type, it has established a methodology that is suitable of wider application to the exploration of aspects, encompassing: assailant characteristics (trajectory of attack and motion); type and angle of attack (in the extreme, stab *vs* slash); assailant intent (force of attack); wider fabric types and combinations (layered clothing); and supported fabric (underlying skin simulants, mimicking a clothed individual). These topics will be explored in future work.

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