CUTTING CRIMES

A group of specialists at the University of Leicester are studying the key factors involved in knife crime – the most common method of murder in the UK. Using forensic engineering techniques, researchers are working to produce data that helps the courts establish whether stabbing incidents are intentional or accidental. Dr Sarah Hainsworth, a forensic engineering specialist in the university's Department of Engineering, outlines the research and wonders if lessons learned from existing and future studies could be used to change people's thinking on knives.

Stabbing is the most common way of murdering someone in the UK. Around 30% of homicides are committed with a knife or other sharp instrument. What is more, of the 17,000 offences of serious violence against the person in 2007-08, 6% involved knives, and a further 4% bottles or other glass.

Stabbing is so lethal because quite a shallow penetration of the body can quickly prove fatal. In a study to develop standards of stab-resistant body armour, tomography was used to show that, depending on the area stabbed, just 20mm of knife penetration gave a 41% chance of puncturing the lungs, over a 60% chance of liver or femoral artery rupture, and even a 6% chance of heart penetration. Figure 1 is a CT scan through the body at chest height, showing how many critical organs lie close to the chest wall.

The force needed to penetrate skin with sharp knives is relatively low. Once the skin has been penetrated, the force required to enter muscle and underlying fat is even lower (see figure 2). Force increases to the point where the skin is penetrated, then rapidly falls off as the knife penetrates the fat and muscle. While some force is still required to drive the knife further into the body, the person with the knife can get the impression that it 'falls' into the body after breaching the skin – which is why knife wounds often penetrate to considerable depths.

RESEARCH CENTRE

At the University of Leicester, effective collaboration between the Department of Engineering and the Forensic Pathology Unit (recognised to be the principal research establishment for forensic pathology in the UK) has been providing new insights into how modern analytical techniques and engineering approaches can help us to understand how crimes were committed and assist the legal system to interpret the complex evidence before the court. We have conducted a range of studies associated with cutting as used in criminal acts, even down to how saws are used to dismember bodies (see box labelled 'Saw Points').

Implements all too commonly used against victims include kitchen knives, folding knives, sheath knives, scissors, chisels, bayonets, kukri, shards of glass, and even sail-makers' awls and samurai swords.

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Understanding the engineering factors associated with cutting or stabbing crimes can prove important both during investigations and when cases come to court. A forensic pathologist is often asked what degree of force would have been necessary to inflict a particular wound and the answer can help the court decide between a tragic accident and a deliberate crime.

It is the engineering disciplines – knowing how hardware is made and operates, and the analysis of forces involved – that can help get at the truth or at least minimise subjectivity (which, in court, may benefit either the defence or prosecution case).

STARTING POINT

I first looked at knife sharpness in 1999 when leading an undergraduate project into materials used to improve edge retention on knives but the subject came into the realms of court work when I was approached by a solicitor to apply this knowledge to stabbing. This was the first time I'd been asked to act as an expert witness in this area, though I've served in that capacity a dozen more times over the last several years.

In knife crime, a number of arguments are often used in court to show that the person

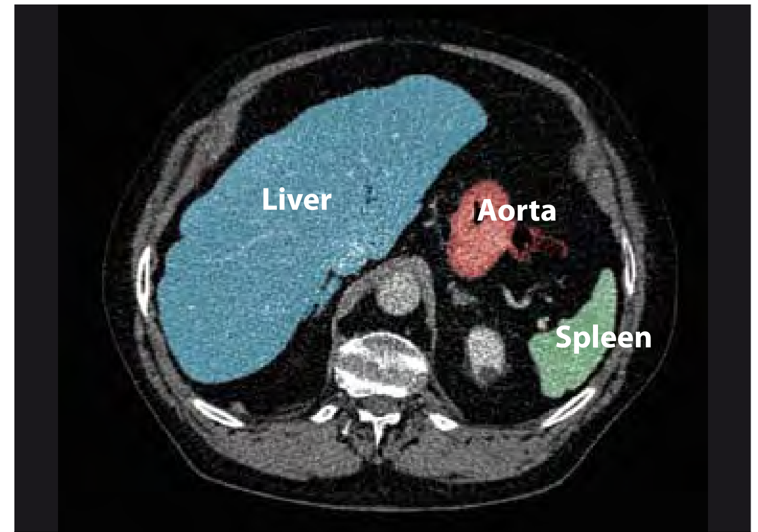

Figure 1: CT scan showing the close proximity of vital organs

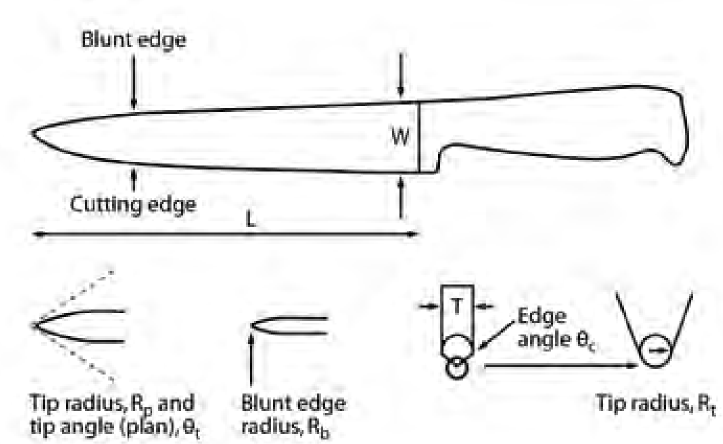

Figure 2: Schematic diagram showing the different parameters to characterise the features of the different knives Figures drawn by Simon Roulstone

Figure 3: A sequence of images taken from the stabbing test with a sharp Sabatier knife © University of Leicester

A Initial contact of knife with pork skin. The skin deflects around the knife tip.
B A later image. At this point, the skin has deflected considerably, and the tip has just penetrated through the skin. The knife now starts to slide into the flesh.
C Further penetration of the knife into the flesh. At this point, the sharpness of the edge becomes important for further sliding into the pork leg. Note that there is some additional deflection of the skin.

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stabbing did not intend to inflict a severe wound. One of the legal defences, for example, may be that the knife was particularly sharp and therefore easily (and by implication accidentally) penetrated the skin. Our work, using more quantitative information from drop testing (see below) along with measurement of the blade tip sharpness and edge profile, can say with some accuracy whether or not this defence is reasonable. If a blade is proven to be blunt, then the court has the necessary information to judge the degree of violence in a particular case, and if the person is found guilty, sentence appropriately.

By applying our techniques and building on existing knowledge and capabilities, our work is increasingly being used to assist the court. While studies of knife crime to date at Leicester (and elsewhere) have been through small projects, I'm hopeful that our work will lead to more funding and bigger projects with broader scope.

Table 1: **DESCRIPTION OF THE KNIVES TESTED**

Knife	a	b	c	d	e
Manufacturer:	Sabatier	Kitchen Devils	Acero	Sabatier	Unknown
Condition	New	New	New	Used	Used
Knife type	Flexible carving/ filleting	Cook's knife	Carving knife	Carving knife	Cook's knife
Blade type	Single-edged plain ground	Single-edged plain ground	Single-edged plain ground	Single-edged plain ground serrated on blade	Single-edged plain ground at tip
Sharpness of tip (qualitative)	Extremely sharp	Extremely sharp	Extremely sharp	Extremely sharp	Moderately sharp to blunt
Sharpness of cutting edge (qualitative)	Extremely sharp	Moderately sharp	Extremely sharp	Moderately sharp	Moderately sharp to blunt
Radius of tip on blunt edge of blade (mm)	0.022	Triangular tip geometry	0.0367	0.061	0.261
Tip angle (plan)	51.5	54.3	46.7	58.6	64.2
Tip radius (Rp) (mm) (plan)	Triangular	0.892	0.121	0.383	0.456
Edge angle	48.2	44.9	30.7	20.7	33.4
Edge radius (Rt) (mm)	Triangular	0.023	Triangular	0.025	0.021
Weight of knife (g)	108.1	100	191.2	104	159

Five different kitchen knives tested for penetrability

CUTTING EDGE

Our research so far has covered which factors influence the effectiveness of a particular knife as a stabbing weapon, the aim being to move from a qualitative to quantitative assessment of how effective a particular knife would be for stabbing.

Pathologists usually have categories for the force required to produce stab wounds – slight pressure, moderate force, or severe force. Since this depends on a range of factors – like the type and sharpness of the weapon, the area of the body concerned and alignment of the blade with the cleavage lines of the skin, the angle of attack, and the relative movements of the people involved – the estimation of the actual force employed in a stabbing is highly complex.

One area where quantification is more tractable is in assessing the sharpness of an implement or weapon. Carving knives are the most commonly used in stabbing incidents, particularly during domestic crimes, but also for fights in public places as they are easy both to obtain and dispose of.

HOW SHARP IS SHARP?

In looking at how to quantify sharpness in a reproducible way and relate this to the effectiveness of a knife for stabbing, we have utilised two major techniques: the use of high-speed video to understand the mechanism by which knives penetrate skin; and a drop testing rig to quantify a knife's ability to penetrate foam, relating this to the characteristics of the knife. Foam or pork are used as a substitute for human skin, although pig skin is slightly tougher than our own.

High-speed video testing for sharp knives shows there are a number of stages by which the knife penetrates the skin (see figure 3). The first contact sees the skin initially deflect elastically. Then, at a critical contact stress, the knife penetrates the skin; the critical contact stress for penetration is related to the sharpness of the tip of the knife. Once the knife has penetrated the skin, the sharpness of both the tip and the blade edge become important in determining how much further the knife will penetrate.

When blunt knives contact the skin, the video records a much greater degree of elastic deflection of the skin than for a sharp knife – and the critical contact stress for skin penetration may or may not be reached, depending on the degree of force applied to the knife.

BLADE VARIATIONS

The shape of the knife blade is also relevant; bread knives with a 'sheep's-foot' geometry show large elastic deflections of the skin. In fact, it is often very difficult to get these to penetrate the skin, yet bread knives have been used to stab people to death. The geometry and characteristics of each individual knife need to be determined before drawing conclusions about their ability to penetrate the skin.

A collection of knives, seized by police in a raid carried out in May 2008
© Lewis Whyld/PA Wire

FORENSIC ENGINEERING

A definition of forensic engineering is the investigation of materials, components, structures or products that have either failed or do not function as intended. And a forensic engineer brings practice-based, experience-led knowledge to bear on the engineered product that goes far beyond basic scientific concepts.

Engineering failures can range from the mundane corrosion of a car's body panel, to the tragedies related to the rail track failure at Hatfield or the Concorde crash in Paris. When we want to find out what happened, it is the role of the forensic engineer to trace the cause of the incident, whether it lay in a manufacturing defect, poor operation, or inadequate design.

Engineering failures may involve death or injury to large numbers of people. 'Forensic' strictly implies a legal aspect to the investigation – and a forensic engineer's findings may be used in criminal law proceedings – but the term is just as often used more loosely to cover investigations that do not lead into the court room.

Forensic engineers contribute their expertise in a number of fields – from major incidents that may, for example, close an industrial plant, or where there is litigation over product failures or patent disputes, right down to personal injury, investigating what caused a ladder or bicycle chain to break. Or, as in this article, the engineer's work could be working with forensic pathologists on recent deaths or forensic anthropologists if bones alone are left to examine.

SAW POINTS

We categorise striations on the kerf [cut] wall three ways – as Type A, which occur during the pull stroke of the saw, Type B, which are finer and formed on the push stroke, and Type C that are irregular and caused by imperfections along the leading edge of the saw tooth.

Some of the University of Leicester's research pedigree in 'cutting' crimes has been to identify saws, in particular hand saws used in the macabre practice of dismemberment, which is sometimes used to prevent identification of murder victims, make transportation of remains more manageable, or make it difficult to determine the cause of death.

Figure 4 shows the definition of the terms used in characterising saw marks. 'Witness marks' are typically found on the cut face or floor and give useful information about the tool or weapon that made them. False start kerfs (cuts) are commonly found where an attempt to cut through the bone has only been partially successful. The width of these marks can be used to help narrow down the type of saw used, but they do not allow us to uniquely identify the saw or weapon.

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Taken together, Type A and B striations can give a strong indication of the type of saw used in the crime. If a saw has been linked to a crime, matching the Type C striations from a test cut to the cut surface recovered from the crime can give definitive confirmation that a particular saw was indeed the one used.

Tests involving four people were undertaken with nylon rods – a medium that shows Type C striations well – to see if cuts could be matched for particular saws. Three of the participants were male – two of them right-handed and competent saw users, one left-handed with little previous experience of saw use. The fourth was a novice female sawyer. Figure 5 demonstrates how we can successfully match the striations made by the same saw but different sawyers.

Each participant was also asked to make a cut in a nylon rod with a previously unused handsaw. In each case the saw that had made the cut could be correctly and uniquely identified. For tool mark analysis, a greater than 60% correlation between striations is considered proof of positive identity. Type C striations can typically be matched with a higher percentage correlation still, showing that this is a robust method of tool-mark analysis – as is being able to distinguish between the same brand and type of new saws. This is the first method that has been successfully used to uniquely identify saw marks to a particular saw and is a major advance in this area.

Following success with knife and saw studies, the University of Leicester's expert team is currently applying its knowledge to research aimed at characterising the forces required for stabbing with blunt weapons, such as screwdrivers, pens, scissors, chisels, and keys.

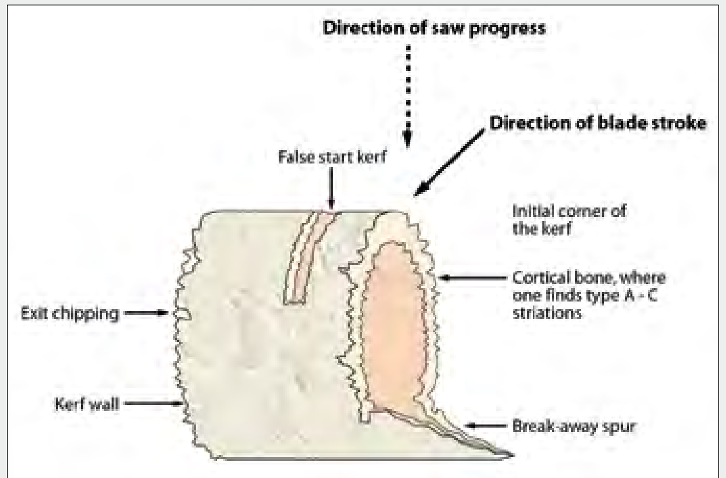

Figure 4: Types of marks that are typically left on the kerf (cut) wall. The width of false start kerfs can be used to help identify the type of saw that may have been used but cannot be uniquely used to identify a saw. Striations on the kerf wall can be used to identify the number of strokes, number of teeth used for cutting and for uniquely identifying the saw Redrawn by Simon Roulstone

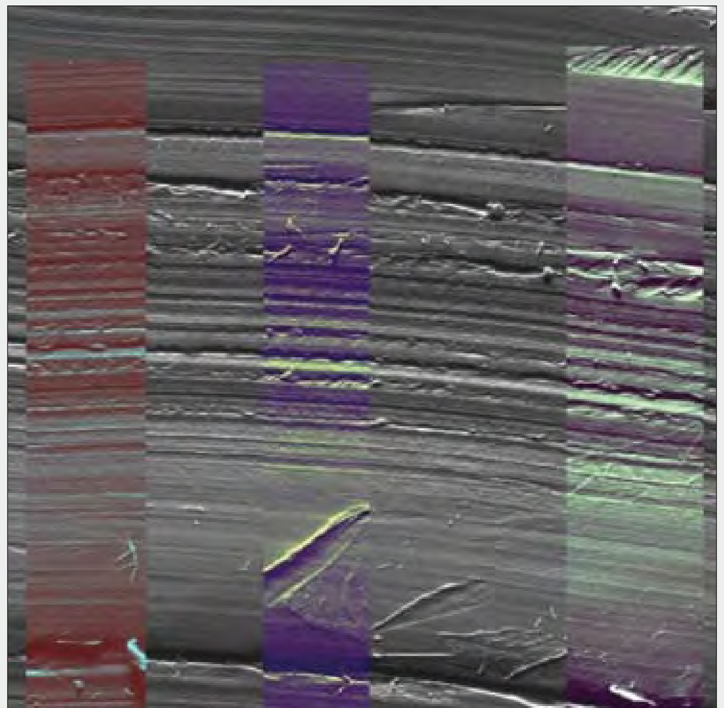

Figure 5: An environmental scanning electron micrograph image with three inset images showing our ability to match Type C striations. The three inset images (shown by the different colours on the image) are from marks made by the same tool and show the excellent correlation that we are able to achieve between saw marks made with the same tool but different sawyers © University of Leicester

ESEM – A KEY FORENSIC TOOL

Scanning electron microscopes (SEMs) are widely used in research to characterise materials and microstructures, by scanning a beam of electrons across the surface of a specimen. Traditionally, such microscopes need the sample to be placed in a high vacuum, non-metallic materials requiring further preparation by applying a coating of gold (applied by vapour deposition) to provide a conducting surface for the electrons and to avoid localised electrical charging of the surface that would prevent imaging. For forensic work, which clearly calls for detailed information to be gathered without in any way altering the object being examined, modern environmental scanning electron microscopes (ESEMs) have made big changes in the way in which we can analyse materials.

SEMs reveal information in various ways by the interaction between the electron beam and the specimen. Electrons are 'reflected' back from the sample depending on the elements and compounds present, X-rays are generated that provide compositional information, but the most commonly-used information comes from electrons that are knocked out from the surface of the sample, as the signal produced by these electrons can be used to reconstruct the topography of the surface.

In effect, what this means is that an SEM can produce an image of a surface at much higher magnification than an optical microscope, with a much higher depth of field.

The ESEM, however, uses novel designs of detectors and vacuum systems to allow the sample to sit in a relatively low vacuum, or even in an environment such as water vapour which dissipates the electrical charging. It is this feature of ESEMs that makes them ideal for forensic studies, as there is no requirement to alter the artefact for examination.

Figure 6: Environmental scanning electron microscope image of a knife impression in cortical bone © University of Leicester

Our drop tests have demonstrated a good correlation between the blunt edge tip radius of a knife and the depth of penetration into foam or pork. While we cannot simulate exactly the combination of factors in an attack, the controlled conditions of drop tests do record impact velocity, energy and momentum, and so deliver a faithful, robust and reproducible comparison of knife sharpness.

We have tested a wide range of knives with differing blade thickness, geometry, and edge types (ie plain or serrated) and the following factors are important for determining a knife's ability to penetrate skin:

- Blunt edge tip radius: gives a good indication of its ability to penetrate into foam or the body (smaller tip radii giving better penetration).
- Blade thickness: slender filleting knives, for example, penetrate more easily than thicker blades.
- Blade geometry, in particular the shape of the blade's tip: knives that taper to a point are more effective at penetrating than profile 1, even if the blunt and sharp edge tip radii are identical for both profiles.
- Edge sharpness: helps continued penetration once the skin has been breached.

We have established a good database with a register of quantified sharpness and penetrability of various knives – and can usually place a knife within this scale, which takes some of the subjectivity out of the quantification of force in stabbing incidents.

BLUNTING KNIVES' IMPACT

We are hopeful that this and future work will be useful in informing future knife design. We've focused on kitchen knives, as these are often used in stabbing, particularly in crimes of passion where a knife may be readily to hand. Since the knife tip is fundamental to stabbing, more could be done to fabricate rounded ends for use in the kitchen, since the tips are usually unimportant for food preparation, with the exception of filleting fish and meat. In delicatessens and carveries for example, employers often use blunt-ended knives for health and safety reasons; while the blade needs to be sharp to carve meat, the tip does not need to be sharp or pointed, so blunt-ended knives are used to minimise the risk of injury to employees.

People may need to be re-educated in their perceptions of sharpness, but it is fairly certain that rounded tips on kitchen knives would inevitably save lives by reducing the number of both fatal accidents and intentional stabbings.

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Dr Sarah Hainsworth is a Reader in Materials Engineering at the University of Leicester and Director of the University's Advanced Microscopy Centre. Her research interests are in forensic engineering, automotive tribology, microstructural evolution in power plant materials (steel and Ni-based superalloys) and materials characterisation. She was the 2008 recipient of the Institute of Materials, Minerals and Mining Rosenhain Medal.

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