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ORIGINAL ARTICLE

Stabbing energy and force required for pocket-knives to pierce ribs

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Abstract
Purpose In addition to reconstructing the course of events, the medical examiner will often have to answer questions regarding the force necessary to inflict a certain injury in stabbing incidents. Several groups have examined the force needed to penetrate soft-tissue and clothing; however, no studies addressing the energy needed for penetrating ribs exist. Therefore, we decided to investigate this force on an animal model.
Method Ribs from healthy, 8 to 10-month-old pigs were used as a substitute for human ribs. These ribs were then stabbed either transversely or longitudinally with two different pocket-knife blades, namely a Swiss Army pocket knife and a sturdier pocket knife (Classic Schnitzmesser, Herbertz Solingen) dropped from a drop-tower at defined heights and therefore defined energies.
Results Longitudinally orientated stabs showed complete piercing of the ribs at approximately 11 Joules (J) or with a stabbing force in excess of 906 Newton (N) for both blade types. Transversely orientated stabs, however, displayed complete piercing between 11 and 16 J, or in excess of 1198 N, with the sturdy pocket knife tending to require a little more energy than the Swiss army pocket knife.
Conclusions Young adult porcine ribs are completely pierced by pocket knife blades at energies between 11 and 16 J. Assuming the porcine ribs are comparable to those ribs of young adult humans, our results indicate that a complete penetration of the chest wall through the ribs by stabbing with a pocket knife is rather easily achieved.

Keywords Stab energy · Stab force · Pocket-knife · Rib piercing · Forensic

Introduction

Stab injuries are frequently encountered in physical disputes and are the most common method of committing homicide in the United Kingdom [1, 2]. Knives are used in most stabbing cases, although scissors, screwdrivers, or glass shards may also be employed, albeit on a rarer basis.

Regardless of whether the victim survives, the medical examiner must try to reconstruct the course of events that led to the injury. One of the cardinal questions in a stabbing case revolves around the energy required to inflict a certain injury. The answer to this question may influence a court's opinion as to whether the stab occurred to severely injure or kill the victim, or whether the stab occurred accidentally.

Several studies have addressed the question of stabbing force involved when penetrating skin and soft tissue with knives [3–6] and the sharpness of knives [7] as well as the force required for penetrating clothing [8].

Not surprisingly, the skin is the most stab-resistant soft tissue. Musculature is somewhat less resistant and subcutaneous fat presents a very limited resistance. O'Callaghan et al. [4] discovered that human skin, fat, and muscle require a maximum stabbing force of 95.5 N, 2 N for fat

In loving memory of my father Werner Bolliger, PhD, 1941–2016.

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alone, 37.5 for musculature alone, and 35 N for fat and muscle together. According to Nolan et al. [8], a cotton t-shirt requires approximately 8 N, and a hoodie in combination with a t-shirt requires as much as 74.35 N for penetration.

Bones can also be stabbed through. Oesterhelweg et al. [9], for example, describe a case where a victim suffered two stabs through the skull with a pocket-knife. Although this is a rare finding, rib injuries are, by contrast, frequently encountered. In court we have been repeatedly asked how much energy is necessary to pierce ribs. To our knowledge, there are no studies dealing with the energy required for a knife to penetrate a rib, which is why we decided to investigate this energy on an animal model with ribs comparable to humans.

We experimentally inflicted stab wounds to porcine ribs with a defined stabbing energy, using either a Swiss Army pocket knife or another pocket-knife with a sturdier blade, namely the Herbertz classic pocket-knife.

Materials and methods

Incomplete rib cages of approximately 8 to 10-month-old pigs were bought from a local butchery. The ribs of the healthy young adult animals were surrounded by musculature, but more or less devoid of fat and lacked skin completely. The ribs were separated from each other by cutting through the middle of the intercostal musculature.

The blades of either a Swiss Army pocket knife (Victorinox A 3610, Victorinox AG, Ibach-Schwyz, Switzerland) with a blade length of just over 6 cm (Fig. 1), or another pocket-knife blade measuring 9.5 cm (Classic Schnitzmesser, Herbertz, Solingen, Germany) (Fig. 2) were fitted to a drop-tower plunger weighing 3215 g, a mass roughly corresponding to an average adult human arm. The plunger with the blade was dropped onto a fresh porcine rib from a certain height based on the calculation of the striking energy as described previously [10] (Fig. 3). The blade was dropped in such a manner that it struck the rib either at a right angle (9 times with the Swiss Army blade and 11 times with the Herbertz blade) or in a longitudinal direction (4 times each with the Swiss Army blade and the other blade) to the long axis of the rib (Fig. 4a, b), and the penetration depth was noted. The blades were wiped clean with paper towels after every stab.

Fig. 1 Swiss Army pocket-knife

Fig. 2 Herbertz classic Schnitzmesser pocket-knife

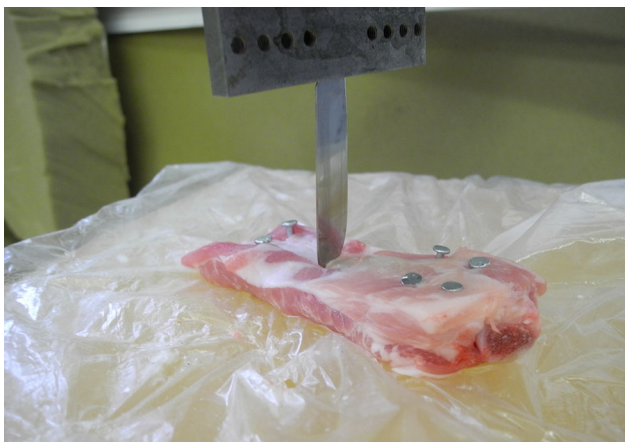

Fig. 3 Swiss Army pocket-knife blade, mounted on the drop-tower plunger, striking a pork rib with musculature and connective tissue perpendicularly

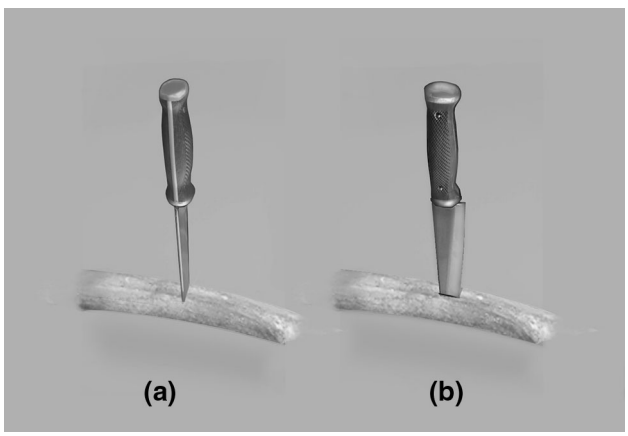

Fig. 4 Schematic depiction of the stabbing orientation. **a** Perpendicular/transverse stab. **b** Longitudinal stab

In cases where the blade did not completely pierce the rib (and thus a penetration depth was known), the average stabbing force was calculated. This force, given in Newton (N), was calculated by the formula energy (in J) divided by the penetration depth (in m).

Results

With the Swiss Army knife, stabbing energies of 12 J were sufficient to pierce the ribs completely in stabs inflicted transversely (Table 1). With 11 J, a complete piercing of the rib was not always possible. Of the two stabs inflicted with 11 J, one stab was completely sufficient, while the other stab only managed to penetrate the rib by 12 mm. Longitudinal stabs (Table 2) with the Swiss Army knife provided similar results. At 10 J, the ribs were incompletely pierced, whereas stabs delivered with 12 J invariably pierced the ribs completely.

Transverse stabs (Table 3) with the Herbertz pocket knife blade did not show quite as clear-cut results. Although 16 J invariably led to complete rib piercing, and energies of 11–13.5 J were generally able to pierce the rib, there was one outlier at 13.5 J that did not. Longitudinal stabs with the Herbertz pocket knife (Table 4) demonstrated that 10 J led to incomplete rib piercings and 13.5 J enabled complete penetration of the rib. The average stabbing forces over the distance of deceleration of the blade necessary for completely piercing the ribs were greater than 906 N with the Swiss Army knife blade and greater than 1125 N with the Herbertz pocket knife.

Discussion

Despite the small number of cases, a cautious determination of the threshold necessary for a knife-tip to completely pierce a rib is possible.

Both knife-blades, the Swiss Army knife and the Herbertz knife, displayed complete piercing of the ribs in longitudinal stabbings at approximately 11 J.

This rather clear-cut threshold of 11 J was not quite as evident in the transverse stabbings with the Swiss Army knife and the Herbertz knife. Stabbing with 11 J displayed both complete and partial piercing. Here, one can deduce that the threshold for a complete penetration of the rib is between 11 and 12 J. The Herbertz blade, however, showed that energies of 11 and up to 13.5 J do not necessarily completely pierce the rib. Here, a threshold is only evident at 16 J, an energy level that invariably led to a complete piercing.

Why transverse stabbing produces a less clear-cut, all-or-nothing threshold is unclear. One possibility is that ribs, by virtue of their bent shape, have different pressure resistances. A cranially located rib is curved more than a more caudally situated rib. This location may affect the transverse stabbing resistance more than the longitudinal stabbings, perhaps by a certain glancing component.

The mean stabbing force necessary for complete piercing of the ribs was greater than 906 N with the Swiss Army knife and greater than 1198 N with the Herbertz knife. O'Callaghan et al. [4] demonstrated that the mean maximum penetration force for skin, fat, and muscle is 49.5 N. These results show, not surprisingly, that the only real resistance a thorax shows toward knife stabs are indeed the ribs and not soft-tissues.

The stabbing energies presented here are, as absolute numbers, not very helpful when having to describe a stabbing at court. If one regards the equation $E = mgh$, however, where m designates the mass (in kg), g the gravitational acceleration (9.81 m/s), and h the height (in m), an energy of 11 J equals the energy necessary for lifting a mass of 1.12 kg by 1 m.

In other words, this force, which is equivalent to lifting a modest hand weight from waist high to overhead, is easily achieved by an adult of either sex and of ordinary strength.

Admittedly this study has several limitations. First, the number of stabs is too small for exhaustive statistical analyses, and second, one may argue that porcine ribs are not comparable to human ribs with regard to stab resistance. However, as porcine ribs have similar thicknesses to human ribs, we assume that they possess comparable physical properties.

Table 1 Swiss Army knife, transverse stabs

Energy (J)	Force (N)	Weight (kg)	Drop height (m)	Stab depth (mm)
7.3	906	3.215	0.23	8
9.5	793	3.215	0.302	12
9.6	801	3.215	0.305	12
10.7	893	3.215	0.34	12
10.8		3.215	0.344	Complete
12.0		3.215	0.38	Complete
12.0		3.215	0.38	Complete
12.1		3.215	0.383	Complete

Table 2 Swiss Army knife, longitudinal stabs

Energy (J)	Force (N)	Weight (kg)	Drop height (m)	Stab depth (mm)
9.6	480	3.215	0.305	20
9.6	801	3.215	0.305	12
12.0		3.215	0.38	Complete
12.1		3.215	0.383	Complete

Table 3 Herbertz pocket-knife, transverse stabs

Energy (J)	Force (N)	Weight (kg)	Drop height (m)	Stab depth (mm)
9.5	412	3.246	0.298	23
9.6	1198	3.246	0.301	8
10.8	1082	3.246	0.34	10
10.8		3.246	0.34	Complete
12.2		3.246	0.382	Complete
12.2		3.246	0.382	Complete
13.5		3.246	0.4.23	Complete
13.5	1125	3.246	0.424	12
13.5		3.246	0.423	Complete
15.9		3.246	0.5	Complete
16.0		3.246	0.502	Complete

Table 4 Herbertz pocket-knife, longitudinal stabs

Energy (J)	Force (N)	Weight (kg)	Drop height (m)	Stab depth (mm)
9.6	502	3.246	0.3	19
13.4		3.246	0.42	Complete
13.4		3.246	0.42	Complete
15.8		3.246	0.496	Complete

Another possible limitation is that the ribs we tested were devoid of skin and overlying fat. According to O'Callaghan et al. [4] the mean maximum penetration force of skin, fat, and muscle is 49.5 N. In comparison to the well over 1100 N necessary for piercing ribs, we believe that this additional resistance to stabs is more or less negligible.

We therefore believe that our results, despite the above-mentioned limitations, provide an impression of the energy and force needed to stab through ribs and allow for a more quantitative assessment of forces required in stabbings, which can be helpful in court.

Key points

1. Complete piercing of porcine ribs by pocket knives could be achieved at stabbing energies of 11 and 16 J.
2. Porcine ribs were invariably completely pierced at stabbing energies of 1198 N or more.
3. Assuming that porcine ribs are comparable to human ribs regarding sturdiness, ribs can be pierced by pocket knives rather easily.
4. Adults of ordinary strength are easily capable of developing stabbing energies of 16 J.

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