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Dynamics of stab wounds: force required for penetration of various cadaveric human tissues

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Abstract

It is often said that once the skin has been penetrated no further force is required to produce penetration of underlying tissues. This experimental study has used technology which was not available to earlier investigators to examine this issue in detail. The results confirm the importance of skin penetration but indicate that the penetration of other tissues may also require significant force. © 1999 Elsevier Science Ireland Ltd. All rights reserved.

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1. Introduction

Stabbing is the most common cause of homicide in the UK [1]. A question often asked of a medical witness is; 'what was the degree of force involved?', the answer being considered significant in determining the question of an alleged assailant's intent to cause harm. The subjective opinions given by such witnesses has prompted researchers to investigate methods of quantifying the force required to penetrate tissues. Current texts are based on studies performed during the 1970s [2–5], however it is

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difficult to interpret the results from these studies since they are limited in detail because of the restrictions of the then available technology.

Knight described in 1975 [2] an experimental protocol for the investigation of the dynamics of stabbing. An instrumented knife was used to make penetrating wounds near the line of autopsy incisions in cadavers. A simple spring-based force-measuring knife-holder consisting of two perspex boxes; one moving longitudinally along the length of the other, two springs resisting this movement was constructed and the system calibrated by loading the device with known weights and marking the deflection of an external pointer. Knight reported that:

> *During the experimental work, it became apparent that the skin was by far the most resistant tissue. Once a knife penetrates the skin, no further force need be applied to cause rapid penetration of the subcutaneous tissues and any underlying organ, except bone or calcified cartilage.*

The observation is perfectly valid but its interpretation needs further examination when one considers the apparatus used. The spring within the system would be compressed as the 'knife tip' pressed on the skin 'storing' energy: at the point of penetration that 'stored' energy would produce a force in excess of that required to penetrate any tissue with a resistance less than that of skin. What the experiment showed, therefore, is that skin is more resistant to penetration than subcutaneous fat or muscle.

Green [3] also constructed a spring-based instrumented knife, confirming Knight's findings, and recording graphically, using a force platform and an analogue storage oscilloscope, the forces required to produce wounds. Calibration was performed by laying the cadavers on the force platform and dropping known weights from a height of 15 cm onto the chest, the oscilloscope gain being adjusted until one division was equal to 5 kg.

In neither study was it possible to measure forces directly, i.e. to measure what really happens at the knife tip as it passes through various tissues. This failing was remedied by Kaatsch [6] in 1993 and by Jones [7] in 1995 who both constructed electronically instrumented knives that incorporated piezo-resistive force transducers. Kaatsch's [6] instrumented knife holder recorded the force applied to the base of a knife whilst Jones [7] sandwiched the transducer between the handle and the blade. Both author's performed stabbing trials on pig tissues and the results recorded using a computerised data capture system. Jones tested two blades, a sharp kitchen knife and a blunt butter knife and the graphical output recorded showed a multi-peak profile to the wounds; the first corresponding to penetration of the skin layer, followed by a number of secondary peaks. The magnitude of the initial secondary peak, corresponding to penetration of the underlying tissue, was typically 50% of the skin layer penetration peak, suggesting that a significant secondary force was required to produce further tissue penetration after a breach of the primary skin barrier. The recordings of Kaatsch also allowed differentiation between bone and soft tissues.

Output from the force transducer used by Jones was in units of electrical potential (V) rather than units of force (N), therefore preventing direct quantitative comparison with previous reported work. In order to achieve that comparison an investigation similar to that of Jones, but using improved instrumentation to record forces involved in stabbing cadaveric tissues was proposed.

2. Experimental method

An instrumented knife was constructed using a piezo-electric force transducer (Brüel and Kjær type 8200) which was sandwiched between the handle and blade. Any force produced between the handle and the blade was transmitted to the transducer which produced an output in the form of charge (C), the amount of charge produced being proportional to the applied force (tension or compression). The charge output was converted via a signal conditioner (Brüel and Kjær type 2626) to a proportional voltage and down loaded to a high-speed digital storage oscilloscope (Tektronix type 410) and stored on computer hard disk.

Ethical approval was obtained and appropriate fully informed consent given for experimentation involving stabbing of amputation specimens and cadaveric tissue; results were recorded for stabs made into the tissues of the thigh to a depth of ~10 cm (to the hilt of the knife) and through various combinations of dissected tissues:

(a) skin, subcutaneous fat and muscle
(b) subcutaneous fat and muscle
(c) muscle only
(d) subcutaneous fat only.

3. Results

The sample size, mean value and range of the forces recorded for the various stabbing experiments are given in Table 1.

Typical outputs recorded when the knife penetrated the different combinations of tissues are shown in Figs. 1–4.

Table 1
Mean force values recorded for penetration of human tissue

Tissues penetrated	Sample size	Mean force (N)[a]	Force range (N)
Skin, fat and muscle	12	49.5	35–55
Fat and muscle	2	35	35
Muscle only	2	37.5	35–40
Fat only	4	2.0	1–2

[a] Mean force=sum/n e.g. muscle mean force=(35+40)/2=37.5 N. Sum=the sum of the peak muscle forces and n=the sample size.

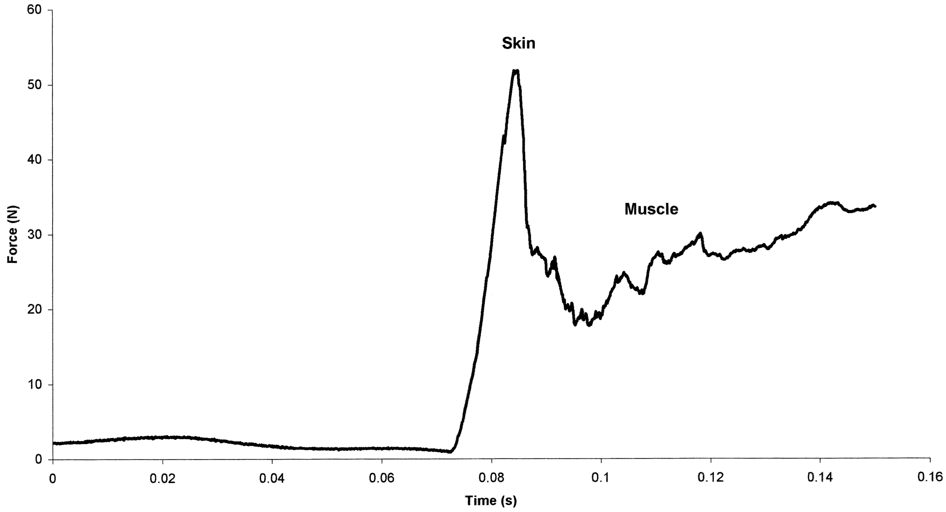

Fig. 1. Penetration of skin, subcutaneous fat and muscle.

4. Discussion

This study set out to determine an accurate force–resistance relation for penetration of a knife into human tissue. It appears from the results that skin provides the greatest resistance to penetration, the mean penetration force being 49.5 N. However, considerable secondary resistance forces not previously recognised were found when the knife was stabbed into the tissues underlying the skin.

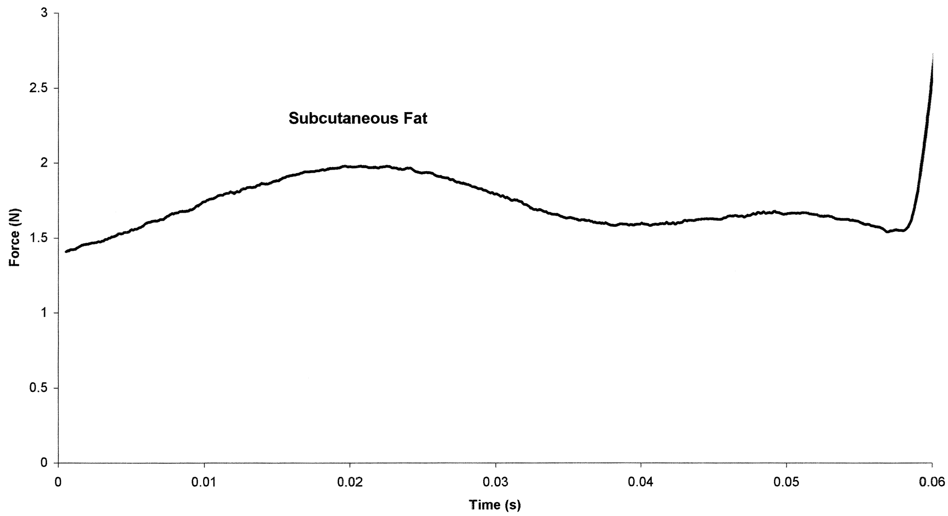

Fig. 2. Penetration of subcutaneous fat.

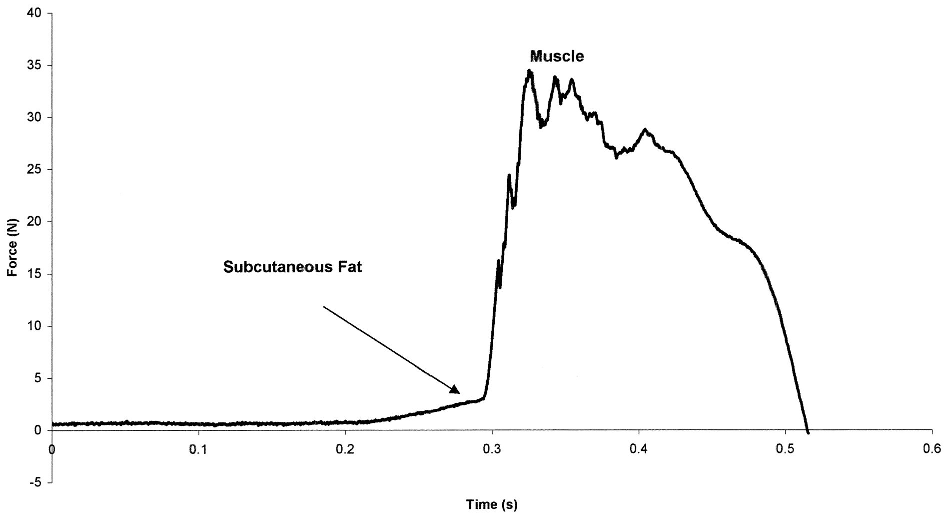

Fig. 3. Penetration of subcutaneous fat and muscle.

Fig. 1 shows the force–time profile recorded for penetration of the instrumented knife into the skin, subcutaneous fat and skeletal muscle combination. The profile shows an initial peak, corresponding to the resistance of skin to penetration, of 55 N (at $t=0.08$ s), the resistive force then decreasing to 20 N (which is ~36% of the initial peak force); as the blade penetrates into the muscle tissue layer the resistive force increases to 40 N (which is ~73% of the initial peak force). This clearly demonstrates that a significant secondary resistive force exists in the muscle underlying the skin.

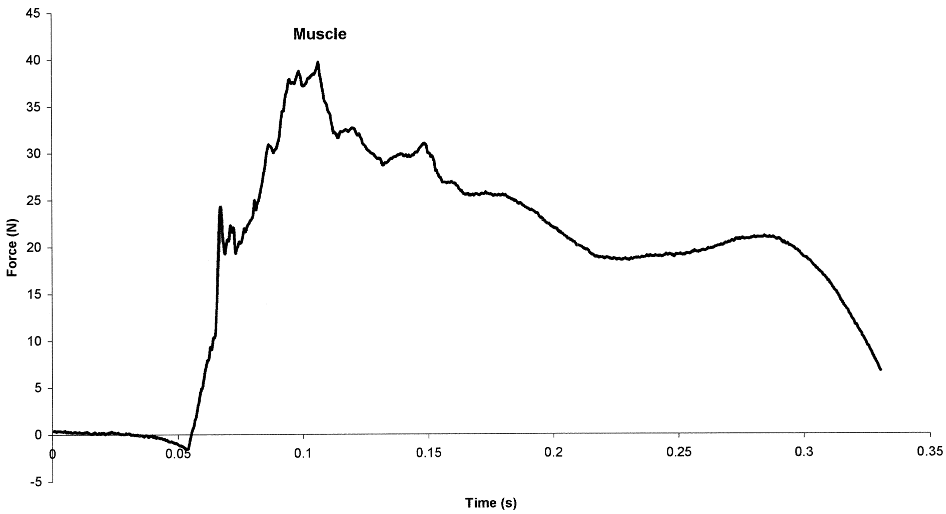

Fig. 4. Penetration of muscle only.

As the resistance of subcutaneous fat to penetration was found to be low in comparison with that of skin and muscle the gain of the charge amplifier was increased in order to provide greater accuracy. The graph in Fig. 2 shows that subcutaneous fat resists penetration until a force of magnitude 2 N is attained implying that deep penetration of fat tissue means very little in terms of force.

In order to measure the resistive force of both subcutaneous fat and muscle the gain of the charge amplifier was then decreased to provide a measurement range of 0 to 100 N (Fig. 3) at $t = 0.3$ s, a peak resistive force of magnitude 2 N (penetration of the subcutaneous fat) is observed, the knife then penetrating the muscle layer, the resistive force of that layer being 35 N.

Finally the layer of subcutaneous fat was removed and the resistive force for muscle only recorded (Fig. 4): the peak resistive force of 37 N was consistent with the values obtained in the previous tissue combinations.

The diminished resistive force as described above for the penetration experiments involving underlying tissues may be easily overcome by the follow through of an assailant performing a stabbing action and can be considered inconsequential for this situation. However resistive force of various soft tissues is of importance when considering penetration due to a projectile, e.g. when a knife is thrown. Since force is directly proportional to energy, the kinetic energy possessed by the projectile is absorbed by the resistive force of the underlying tissues which will result in a reduced depth of penetration.

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