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The Mechanism of Needle Penetration Through a Woven Aramid Fabric

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ABSTRACT
Fabrics that resist needle penetration are important for the manufacture of protective gloves and clothing. Understanding the mechanism of needle penetration through a fibrous structure enables optimisation of protective fabric design. This work investigated the process of low speed penetration of a needle through a woven aramid fabric. Motion image capture of the needle enabled needle position correlation with the needle penetration force profile. The needle penetration force curve had three characteristic peaks and more than 70% of the needle tip was already exposed at maximum penetration force.

INTRODUCTION
Puncture resistant fabrics are widely used to protect workers from needle stick injuries. Needle stick injuries can occur in a wide range of occupations, including the medical industry, law enforcement, corrections, gardeners, cleaners and maintenance[1].

The standard method for determining puncture resistance to a hypodermic needle is ASTM F2878-10 [2]. Although several studies have looked at the hypodermic puncture mechanism in elastomer materials [3, 4], the puncture mechanism of woven aramid fabrics has not been investigated.

The current test method identifies penetration via electrical responses [5], however optical methods, which provide further insight into the penetration process, have not been investigated. This work will investigate the mechanism of puncture and the point of needle penetration with respect to penetration force for a woven aramid fabric using motion video capture.

EXPERIMENTAL
The woven fabric used in these experiments was obtained from a Turtleskin Insider glove (Warwick Mills, USA) and was a plain weave fabric (240end/10cm warp, 480ends/10cm weft).

The needles were a 21 guage (0.80 mm) needle (Terumo Corporation, USA) with a triple lancet design. Five of the needles had their cutting edge rounded from their lancet using a WS Flex 18C P1200 grit paper (Hermes Abrasives, Australia). Both sharp and blunt needle types were tested five times.

Fabrics samples (15 mm x 30 mm) were clamped on either side 20 mm apart under tension using a specially designed rig shown in figure 1. The tension force was 2.3 N applied by a spring between the two mounting blocks. The needle penetration force was measured at 10 mm/min using a 100 N load cell with a 5967 Materials Testing System (Instron Corporation, USA).

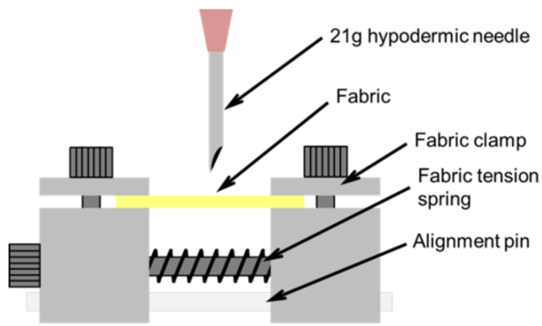

Figure 1 Diagram of needle penetration rig.

Motion image capture was undertaken using a QC3247 USB camera (Digitech Industries, Hong Kong). Images were removed from the captured video using Windows Live™ Movie Maker (Microsoft Corporation, USA)

RESULTS AND DISCUSSION
The applied needle force versus needle displacement measured for each of the needle types tested was plotted (Figure 2). Three distinct force peaks were observed during fabric penetration by a needle. Each peak represents a significant point in the needle penetration sequence as exemplified in Figures 3 and 4, which show the key penetration points. Peak 1 coincided with the needle tip penetration, exposing the tip to the underside of the fabric. Peak 2 coincided with the end of the cutting induced by the needle lancet. Peak 3 could appear as a single peak or a double peak. The single peak represented ejection of the bevel heal from the cut hole. The double peak represented the ejection of the fabric flap from the needle heal liquid tube followed by the ejection of the bevel heal from the cutting hole.

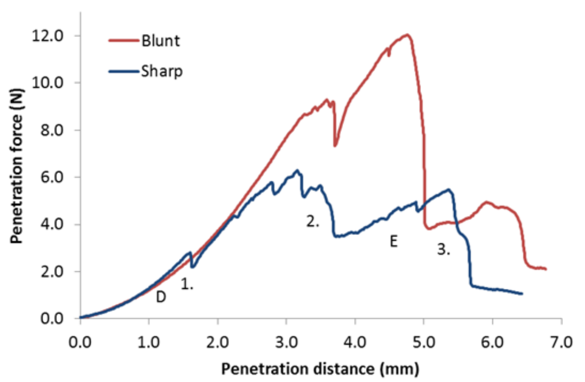

Figure 2 Applied needle force with respect to penetration distance.

The force measured in peak 1 results from the contribution of extension and bending of the fibres during the initial displacement of the fabric (D). Once the needle tip has penetrated the fabric, the remaining force resisting the needle is believed to be from the energy required to move away and cut the fibres to allow a path for the needle to penetrate. There may also be a contribution from the displacement of fibres within the fabric, resulting from the increase in effective size of the needle section as this progresses through the fabric. The peak arising from the end of the lancet entering the top layer of the fabric occurred due to the sudden shape change in the needle from lancet grinding to needle bevel caused by the lancet grinding process. Force/displacement curve comparison for the blunt and the sharp needles revealed the lower load in the lancet cutting stage for the sharp needle, suggesting that the presence of a cutting-efficient edge reduced the force required for the needle to pass through the fabric, substantiating the hypothesis of a fibre-cutting mechanism during needle penetration. The lower cutting efficiency of the blunt needle resulted in a higher force required for penetration through the same fabric.

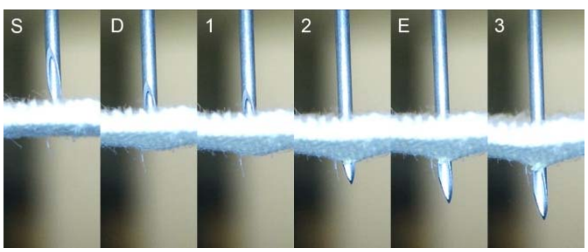

Figure 3 Sharp needle cutting sequence.

Peak 3 was due to the displacement force required to open the penetration hole to allow for the bevel to pass. Once the bevel heal had passed, the surface resistance of the fibres contacting the shank surface still imparted some resistance on it.

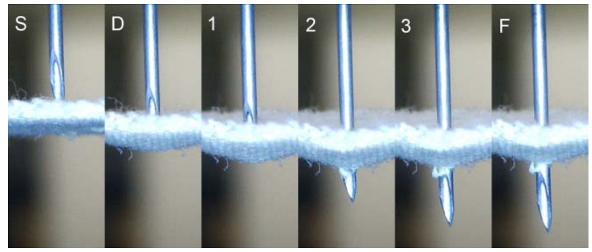

Figure 4 Blunt needle penetration sequence.

For both the sharp and blunt needle tests conducted, needle tip penetration had occurred at under 4 N of force (figures 3 and 4, image 1). By the time of maximum force of penetration at least 70% of the needle bevel was already protruding through the fabric (Figures 3 and 4, image 3). This was similar to that observed by Gauvin *et al* [5] however the penetration distances at the slower test speeds measured visually in this work were higher than those measured electrically by Gauvin *et al*.

CONCLUSION

The penetration of a sharp hypodermic needle through a tightly woven textile fabric normally produces three force peaks associated with tip, lancet top and bevel heal penetration of the fabric. The maximum force of penetration is reached with at least 70% of needle bevel already protruding through the fabric. Test methods should consider exit of the needle tip as an end point for testing, rather than the maximum force recorded during fabric penetration.

REFERENCES

1. O'Leary, F.M. and T.C. Green, *Community Acquired Needlestick Injuries in Non-health Care Workers Presenting to an Urban Emergency Department.* Emergency Medicine, 2003. 15(5-6): p. 434-440.
2. ASTM International, *ASTM F2878-10 Standard test method for protective clothing material resistance to hypodermic needle puncture*. 2010: West Conshohocken, PA.
3. Nguyen, C.T. and T. Vu-Khanh, *Mechanics and mechanisms of puncture by medical needles.* Procedia Engineering, 2009. 1(1): p. 139-142.
4. Dolez, P., T. Vu-Khanh, C.T. Nguyen, G. Guero, C. Gauvin, and J. Lara, *Influence of medical needle characteristics on the resistance to puncture of protective glove material.* Journal of ASTM International, 2008. 5(1).
5. Gauvin, C., O. Darveau, C. Robin, and J. Lara, *Analysis of test paramteres and criteria for charcaterizing and comparing puncture resistance of protective gloves to needles.* ASTM - Performance of Protective Clothing and Equipment: Emerging Issues and Technologies, 2012. STP1544: p. 1-14.