A Finite Element Model Simulating Blunt Puncture of Skin with Screwdrivers and Spherical Impactors

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Summary

A computational finite element (FE) model was developed and validated to simulate various size screwdrivers and spherical impactors puncturing skin. The force required to puncture skin of various thicknesses over an extensive range of impactor cross-sectional areas (CSA) was assessed, which may provide quantitative evidence on determining likelihood of accidental or excessive force in forensic stabbing cases.

Introduction

Violent crimes and acts of self-defense using knives or other sharps account for 22% of all global homicides [1]. However, blunter instruments, such as household tools, have also been used in penetrating cases such as self-defense but lack quantified force data [2]. Few studies have attempted to simulate puncture of skin with sharps but lacked sufficient validation data with biological tissues and did not account for effects of skin thickness and viscoelastic effects at real-world stabbing rates [3]. A well-validated FE model is advantageous to characterize material behavior and failure thresholds of skin in blunt puncture based on skin thickness and impactor CSA.

Methods

An FE model of isolated skin in blunt puncture was developed based on isolated porcine skin in previous experimental studies [4]. The skin was defined with hyperelastic and viscoelastic material properties (Table 1). The outermost nodes of the skin were fixed. The 3-, 5-, and 8-mm diameter spherical impactors [4] were modeled as rigid shell elements with known properties of steel (Table 1). The skin was displaced 25 mm and modeled with a frictionless tiebreak contact. The contact force over time was quantitatively validated using CORA with 18 unique experimental loading conditions for impactor size, skin thickness, and loading rate [4]. Once validated, Hex and Torx screwdriver and spherical geometries with CSA from 6-71 mm^2 linearly displaced the 2-3 mm thick skin at 750 mm/s until element failure, and relationships were assessed with linear regression.

Results and Discussion

The FE model was validated for all 18 loading conditions with a categorically 'good' average CORA score of 0.725. The average maximum principal stress was 57.32 ± 10.15 MPa at failure. Simulated failure force significantly increased as skin thickness increased ($p<0.05$, $R^2>0.9$). Impactor CSA linearly correlated with normalized force ($R^2>0.88$) (Figure 1).

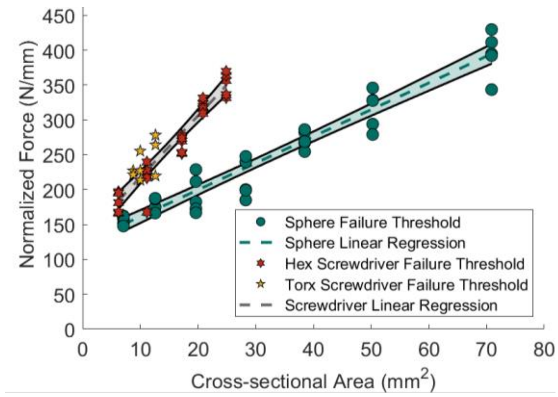

Figure 1: Linear regression of simulated normalized force at failure and cross-sectional area of screwdrivers and spherical impactors.

Likelihood of accidental penetration or excessive force during a stabbing event may be assessed by comparing thrusting force to failure thresholds of skin based on CSA [5]. Simulated thresholds of the Hex3 (439 N) and 3 mm sphere (345 N) into 2.3 mm skin were consistent with experimental screwdriver puncture into porcine tissue (241-473 N) [5], which is comparable to the force of a forceful two-handed push, quantified from volunteer studies [5].

Conclusions

A well-validated FE model of blunt puncture may be used to simulate case-specific geometries and skin thicknesses for evaluation of relative force in blunt instrument forensic cases.

Acknowledgments

Research was supported by MCW/DEVCOM ARL W911NF-21-2-0004 and HHS NIDILRR 90ARHF0006-05-00.

References

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Table 1: Material properties of the skin and steel impactors.

	Mass Density (kg/m^3)	Poisson's Ratio	Young's Modulus (GPa)	Ogden Coefficients	Prony Series Coefficients
Skin	1527	0.49	–	μ=0.505 MPa, α=12	G_1=1.0, τ_1=0.5, G_2=0.75, τ_2=10
Impactor	7750	0.285	200	–	–