Behind Helmet Blunt Trauma Deformation Geometry under Different Helmet Materials

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Introduction

Despite modern combat helmets defeating penetrative threats through attenuating energy transfer via recruitment, deformation, and delamination of the helmet shell material, serious and/or fatal behind-helmet blunt trauma (BHBT) injuries from the impact of the deforming helmet backface against the wearer's head may still occur[1–3].Design of combat helmets must balance protection against penetration and BHBT[4–6] with helmet weight, which is related to other increased injury risks[7–9]. Since the 2010s, newer helmet designs have adopted Ultra-High Molecular Weight Polyethylene (UHMWPE) shells for their lighter areal density than legacy aramid helmets[10] but UHMWPE generally exhibits greater deformation depth than aramid[11,12]. No past studies compare backface deformation geometry between helmets of different materials under ballistic impact.

Objective

Though BHBT has been studied computationally[13–16] and experimentally[17–19], relationships between deformation depth used in current helmet standards and recruitment of deformation geometry is unclear. To address this gap, dynamic deformation profiles are obtained in different helmet shells to compare extent of material recruited under BHBT.

Methodology

Thirty-eight helmets were positioned on Hybrid III ATD headforms and impacted using 7.7 g 9 mm projectiles at 388-482 m/s. Four 150 KVp flash x-ray heads collected 76 flash x-ray images at 70 ns pulse widths from two perspectives and were triggered by a frangible surface contact at the impact site. This x-ray imaging was used to measure backface deformation during the impact event. Projectile velocity was measured by two interleaved Shooting Chrony chronographs and confirmed by high-speed video. Three types of helmets were tested, an older aramid helmet, a newer aramid helmet, and a prototype UHMWPE helmet. To aid comparison against the aramid helmets, UHMWPE helmets were constructed to be dimensionally similar to the older aramid helmet and used identical suspension. Given two perspectives for each of the 38 tests, both perspectives were combined for a total of 76 planar x-ray images. These images were digitized in ImageJ to outline deformation profiles. Coordinate axes were created along the surface of the undeformed helmet using local minima of the deformation profile and perpendicular to the point of greatest deformation depth relative to the surface. Given limitations of 2D imaging, surface area and volume were calculated by rotating the profile. Relationships between geometry and depth were identified using linear regression and then compared using analysis of covariance (ANCOVA) between helmets to visualize extent of helmet material recruited over deformation severity.

Results

For both the ANCOVAs of surface area and volume over deformation profiles of similar depth, the interaction for geometry and helmet type was significant ($P < 0.05$). Given a variable time window (~3 ms) during which the flash x-ray may have triggered, profiles do not represent the moment of peak deformation but capture geometry during the impact event.

Conclusion

Differences between deformation depth at similar volumes and surface areas highlights potential factors that may influence BHBT risk in UHMWPE helmets relative to older aramid helmets. The more pointed deformation also highlights possible future work examining differences in deformation rate given greater deformation of the less recruited shell material.

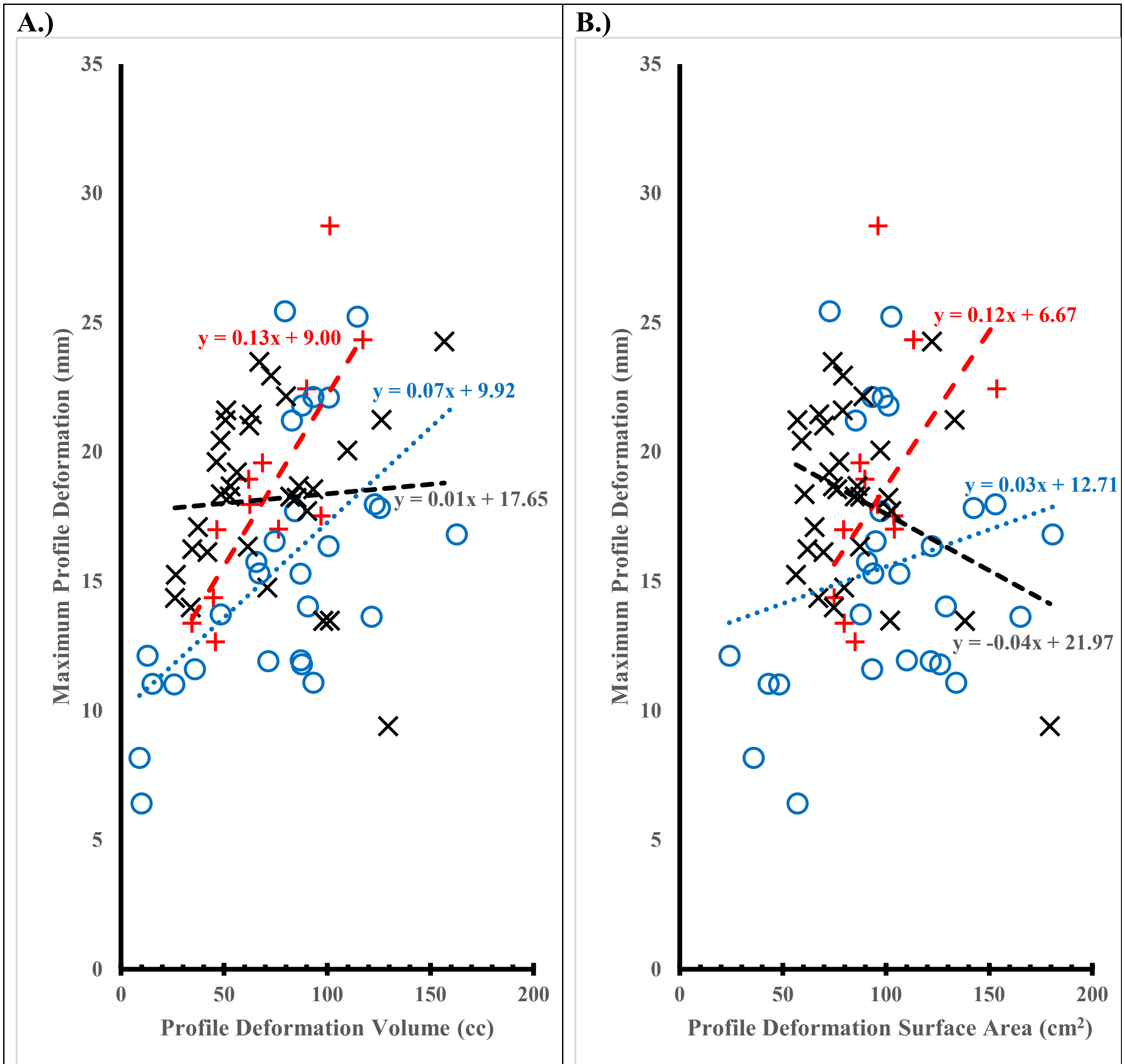

Figure 1. *A) Deformation extent over Volume B) Deformation extent over Surface Area.* (O) *Older Aramid,* (+) *Newer Aramid,* (X) *UHMWPE.*

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