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Title: Concept and material development in tourniquet research for impaled object hemorrhage.

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Introduction: Tourniquet use in combat casualties with limb wounds is common—nearly 40%.[1] Yet, little research exists on tourniquet use to control hemorrhage produced by an impaled object.[2] The objective of this study was to develop simulation materials and wound-hemorrhage concepts for one-handed self-application of a tourniquet to an impaled limb. Our rationale was to screen candidate materials and concepts quickly for what worked well and also to simulate caregiving realistically, so we conceived of a 2D and a 3D assessment model for the respective needs.

Methods: 2D and 3D ways of simulating impaled limbs were constructed to challenge first-aid use of tourniquets. In 2D assessments, graph papers, cardboard cutouts, strings, and kabob skewers mimicked cross-sectional planes of limbs, limb girths, loops of tourniquet band, and impaled objects, respectively. Skewer placements were arranged to vary the degree of ease in loop passage (Likert scale 1 very, very difficult; 7 very, very easy). Challenges were varied to worsen scenarios by adding girth (anthropometry)[3], skewers, boot outlines, and garment cutouts.

For 3D assessments, an investigator used one hand to unwrap a tourniquet from its packaging, manipulated the tourniquet's band to shape it into a loop, passed the loop over the end of a pool noodle (distal thigh sized, diameter 12.3 cm), passed the loop over an impaled knitting needle (length overall, 25.4 cm), and placed the loop 5.1–7.6 cm (2–3 in.) proximal to whichever of the two needle wounds was more proximal. The degree of ease in loop passage was graded (Likert scale 1 very, very difficult; 7 very, very easy). Assessments were made for added girth, needles, boots, and garments.

Results: 2D assessments were made rapidly and repeatedly to indicate whether loop passage was easy. The easy-difficult boundaries were identified for varied configurations of girths, skewers, boot outlines, and garment cutouts; loops stretched to the limit to pass around objects identified boundaries. For example, strings mimicking loops simulated easy passage for small girths, one skewer, boot absence, and garment absence but simulated difficult passage for large girths, multiple skewers, boot presence, and garment presence. Challenges to passage which were conjunctive (multiple, concurrent) readily worsened scenarios. For example, small girth, one skewer, boot absence, and garment presence were more difficult due to the added garment thickness as compared to without garment; at the same time, such difficulty equaled that of change in limb girth of equal thickness but without garment. For assessments of equivalent geometry, the degrees of challenge to passage were equal; the reason why the geometry differed (e.g., girth or garment) did not affect the degree of challenge.

In 3D assessments in use of tourniquets, loops for actual tourniquets were opened and passed. For 30 Combat Application Tourniquets (C-A-T), loops opened into conformable ovals to pass easily; loop size (circumference) averaged 69.8 ± 0.17 cm (mean ± SD [91st percentile of Soldier thighs[3]]); C-A-T instructions for use (IFU) do not denote or restrict to what limb the loop is sized. For 24 Special Operations Forces Tourniquet (SOFTT, 1.5 in. wide), loop size averaged 62.0 ± 2.50 cm ([50th percentile of Soldier thighs[3]]); SOFTT IFU denote that the loop is sized to pass over the user's arm. For one Tactical Mechanical Tourniquet, one Emergency & Military Tourniquet, and one Ratcheting Medical Tourniquet, loop size was 56.8, 88.7, and 79.5 cm, respectively. The Omna Marine Tourniquet as packaged was not configured in a loop; its IFU did not show how to reconfigure the tourniquet for one-handed self-application, but it did show how to apply as so reconfigured.

For one C-A-T, loop circumference was varied by reconfiguring the loop, and its circumference was decreased incrementally by ~1 cm in 30 assessments from 69.7 cm to 37.3 cm; ease of passage was initially very, very easy (7/7) but eventually became very, very difficult (1/7).

Additional assessments of girths, needles, boots, and garments showed that 3D results were consistent with 2D results, although the latter were gathered faster. However, some 3D solutions were not discovered in prior 2D simulations, although after discovery such solutions were easily simulated in 2D; an example was to pass one side of the loop over one end of the impaled object then pass the other side of the loop over the other end of the object. The 3D model was more realistic but slower in screening materials and in developing concepts.

Discussion: Assessments of simulated loop passage over impaled objects led to development of simulation materials and of caregiving concepts. In both 2D and 3D, geometry helped in understanding loop passage and its troubleshooting. The 2D and 3D methods were complementary and not redundant in generating findings which led to developed concepts. Developed concepts included: performance metrics of loop passage, loop size in its passage, loop size differences among tourniquet models, loop size comparisons to limb girths, loop passage challenges other than due to limb girth, and loop passage in the face of multiple, concurrent challenges. A caregiving gap was discovered: a proportion of Soldiers may be unable to pass a tourniquet loop to their proximal thigh, indicating that troubleshooting methods may need to be developed and taught. A deductive consequence of inter-model differences in loop size is that users may need to know about multiple tourniquet models in order to be interoperable among teams, organizations, military services, allies, or partners.

References

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