Characterisation of hit point and wound tract distribution from lethal firearm violence in Stockholm 2021-2024

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Abstract. The design of personal armour systems is based on the assumption that incoming missile threats have a roughly horizontal directivity, and that hits are concentrated to the chest area. This seems reasonable in a military context, with small arms fired at intermediate to long distances. However, in close quarters combat environments, engagements with illegal combatants, or in law enforcement situations, this may no longer be the case. This work investigates possible repercussions of these factors on modern body armour design.
Here we report the results of a multidisciplinary study of lethal shootings in the Stockholm metropolitan area in the period 2012-2023. We characterise the directionality of the observed wound tracts in terms of their corresponding entrance and exit wounds. The majority of the data is collected from civilian homicides, which to a first order approximation represents close quarters combat and intermediate range engagements. Furthermore, in case of multiple wound tracts each wound tract is assessed by an experienced forensic pathologists to characterize the wound as lethal or not.
Preliminary results indicate a presence of entrance wounds for lethal wound tracts outside the area typically covered by body armour, and furthermore that the wound tracts still cause lethal damage to vital intra-abdominal or thoracic tissues. We report observed distributions of hit points and wound tract directionality, to provide the community with an image of the threat of lethal close quarter and intermediate range combat situations.

1. INTRODUCTION

It is a well-known fact that the use of body armour reduces fatality rates in firearm engagement [1], both in a civilian and military context [2]. However, there are also studies that suggests that body armour to varying degrees impair physical performance [2, 3], due the added weight and reduced mobility. This means that the use of, and the design of, body armour systems, especially those with high-weight plates, has to balance the cost of reduced physical performance and the gain of increased survivability. In order to successfully optimize such a trade-off, ballistic threats have to be carefully characterized and evaluated.

The design strategy of body armour is to protect the most vital organs while minimizing weight to maximally maintained mobility [4]. The conventional solution is to add ceramic plates covering the front and back of the thoracic cage, to protect the heart, lungs and to some extent abdominal contents. However, this placement of said plates is made with the assumption that the angular dispersion of incoming missiles is limited, and that the target is in standard anatomical position, exposing either the chest or back areas. In line with this assumption, armed force related gunshot wounds, in abdomen and thorax, are commonly found with lateral entry wounds [5, 6]. Hence, in some cases, the assumptions on missile threat directionality will certainly be sound – such as armed forces fighting from an entrenched position – nonetheless, in close quarter combat, or in a law enforcement environment, more dynamic encounters may occur where the directionality of incoming missiles may be less predictable. In such cases, we propose, the directionality of incoming missiles may more closely resemble those of civilian shootings.

There are numerous studies describing the epidemiology and the characteristics of wounds from firearms based on civilian health care and/or forensic pathology statistics [7-10]. The overall pattern is strikingly consistent across countries and continents [11] . Overall, in civilian firearm-related fatalities head injuries are dominating in relative numbers, followed by thoracic and abdominal injuries [11-16]. This is not surprising as these body regions harbours the main vital organs and large vessels. An important deviation from this pattern is lethal gunshot wounds caused by law enforcement personnel. A retrospective study of such gunshot injuries showed that the main location of potentially lethal entry wounds was in fact the front of the chest [17], followed by the back, the head and abdomen. This highlights an important distinction between trained and untrained shooters, though it certainly also reflects the difference in context where these lethal firearm injuries occurred. However, it

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is worth pointing out that the threat against the law enforcement typically are perpetrators, much like the ones that lie behind the statistics of civilian gunshot fatalities.

In armed forces, fatal gunshot wounds are rare, compared to injuries and fatalities from various explosive devices [18]. This may be related to the increased use of body armour, but the evolving characteristics of the battle field probably is a more plausible explanation [7, 18].

The location of the vital organs is an important component when determining where extra protection is needed, however in this paper we highlight the fact that the projectile may in principle take any number of pathways to reach these vital organs. If a projectile hits a person from an angle not normal to the chest or back plates, it can penetrate into, *e.g.*, the thoracic cavity and cause fatal injuries. As an example: A study by forensic pathologists of 40 people presumably killed by armed forces showed that only a fraction of the observed wound tracts followed a horizontal path, and conversely that a comparatively large portion of wound tracts did not originate in the central front or back of the thoracic cage [19].

All of this highlights the importance to not only account for the actual hit point (the entry wound), but also the pathway, or the directionality, of the wound tract, when characterizing firearm projectile threats.

To address this question 104 wound tracts from gun shots were analysed. They were the result from civilian shootings in the greater Stockholm metropolitan area, from 2021-2024. None of the victims carried body armour. The wound tracts were characterized in terms of entrance and exit points and the directionality of the pathway connecting the wounds. Furthermore, for victims with multiple wounds, each wound tract was evaluated by an experienced forensic pathologist to determine whether it is considered lethal or not. The observed positions of the entrance wounds in this study are in good agreement with those in other studies, with hits in the head, thorax or abdomen, in order of relative lethality. However, analysis of the directionality of the subsequent wound tracts suggests that the directions of incoming projectiles is highly stochastic. Furthermore, many lethal thoracic and/or abdominal injuries was registered in wound tracts that did not exhibit a directionality consistent with the placement of reinforcement plates in modern body armour systems.

2. METHODS

All shot lines included in this study resulted from non-suicidal civilian shootings in the greater Stockholm metropolitan area. A total of 104 shot lines were randomly selected to be included. For each case, the autopsy protocol, associated photographic documentation, and computer tomography (CT) data was analysed and the localisations of the entrance and exit wounds was determined. In the cases where the projectile was retained in the body, the position of the bullet was instead determined. Each wound tract was analysed independently and any combination of injuries are not reported here. In order to be able to compare shot lines across bodies of varying sizes and morphologies, the body was divided into 53 sub-regions (Figure 1) and the position of each entrance and exit wound was assigned a specific region. The entry wound localisation analysis was then performed at this data resolution.

To analyse the directionality of the shot line, each entry and exit wound was given a random location within the region (NX) where it was observed. The pseudo-random localisation (within a sub-region defined in Fig. 1) of the entrance and exit wounds were then projected onto a three-dimensional human model. This model was based on the geometries of the low resolution human computer model ComputerMan [20]. The directionality of every wound tract was then characterised by two angles, where the first angle refers to rotation around the longitudinal axis of a standing person, where a front-to-back direction is 0° and where positive rotation is related to increased angle value. The second angle refers to elevation where a horizontal path is defined as 0°, straight from above is +90° and from below is -90°.

3. RESULTS AND DISCUSSION

104 gunshot injuries were analysed, and these resulted in a total of 208 external wounds or retained bullet, 47 (45 %) wound tracts was considered lethal. The overall localisations and lethality are summarised in Table 1. In order to determine the mechanism of lethality in this dataset, the positioning of the entry and exit wounds were determined and analysed.

For each wound the localisation was determined with a higher resolution than in Table 1, following the anatomic division in Fig. 1. In general, the distribution of wounds (entry and exit) involves all body regions, save the distal parts of the extremities, Fig. 2.

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3.1. Localisation of entry and exit wounds

Next, the position of entry wounds was analysed, both in order to be able to compare with other data, but also because the position of the entry wound is related to the feasibility of covering the entrance wound with body armour.

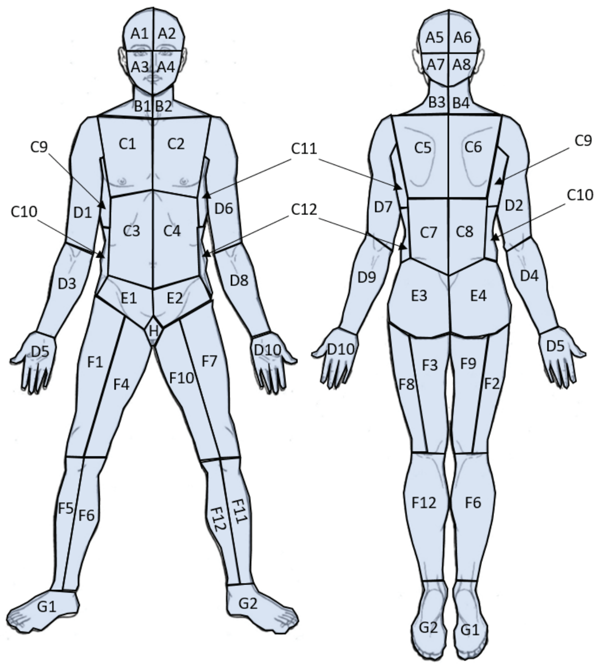

Figure 1. The division of the body into regions. There are 7 regions A: Head, B: Neck, C: Torso, D: Upper limbs, E: Pelvis and buttocks, F: Lower extremities, G: Feet and H: Outer genitalia. Each region is then further divided into sub-regions (save the outer genitalia).

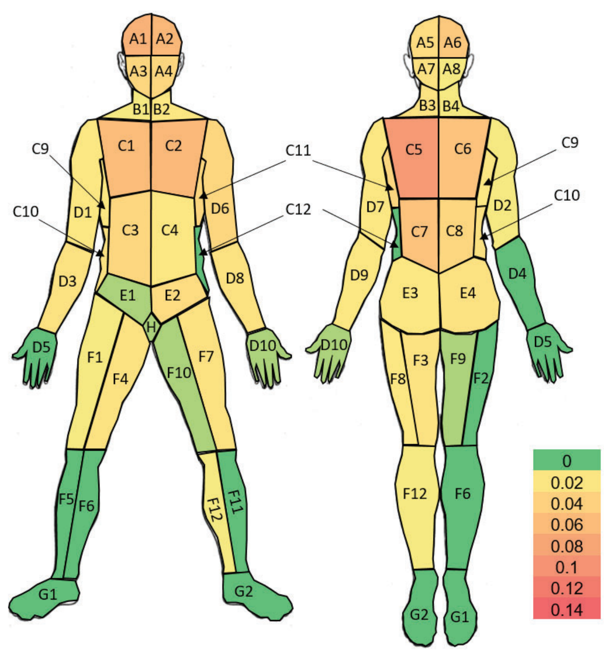

Figure 2. Relative localisation distribution of all gunshot related wounds in this study. Total number of wounds (entry and exit/retained bullet) are 208. Colour represents fraction of wounds in each area.

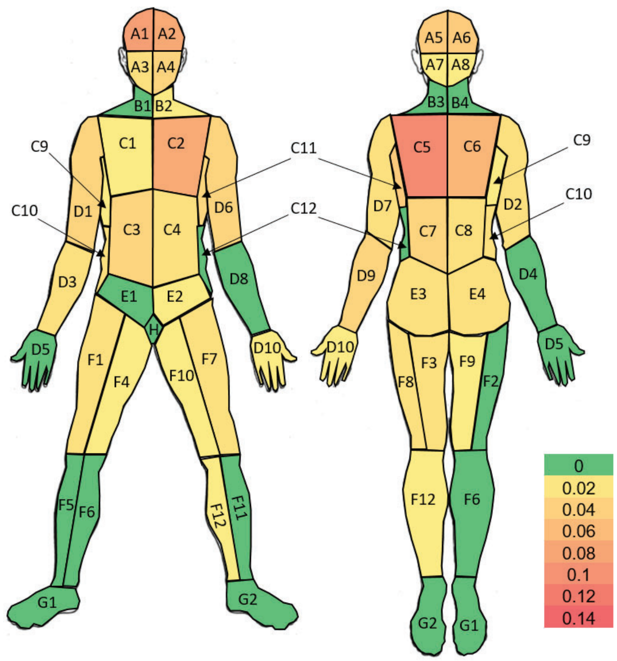

Figure 3. Relative localisation distribution of entry wounds in this study. Total number of entry wounds are 104. Note the similarity in distribution between entry wounds alone and entry and exit wounds together (Fig. 2).

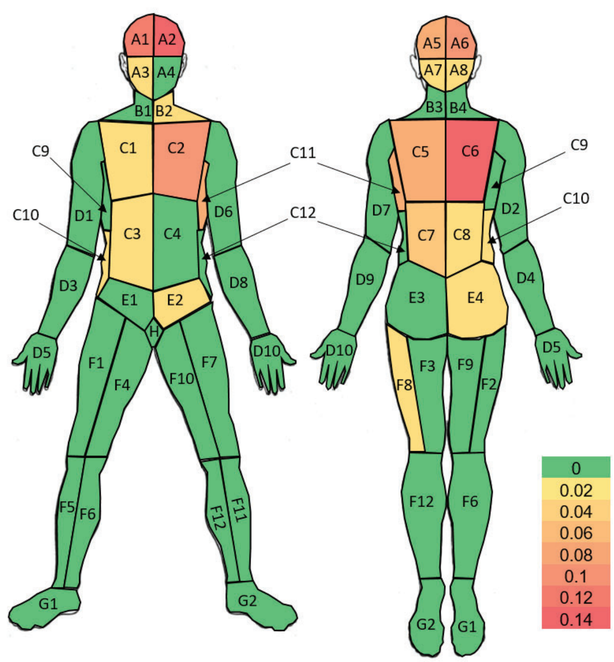

Figure 4. Relative localisation distribution of entry wounds related to lethal injuries in this study. Total number of lethal entry wounds are 47. It is clear that lethal injuries are associated to entry wounds in the proximity of the regions harbouring the vital organs.

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Interestingly, the distribution of entry wound localisations in Figure 3 overlaps reasonably well with the general distribution of wounds in Figure 2. This indicates that there are no specific angle of incidence, but rather that the shot lines seem uniformly distributed.

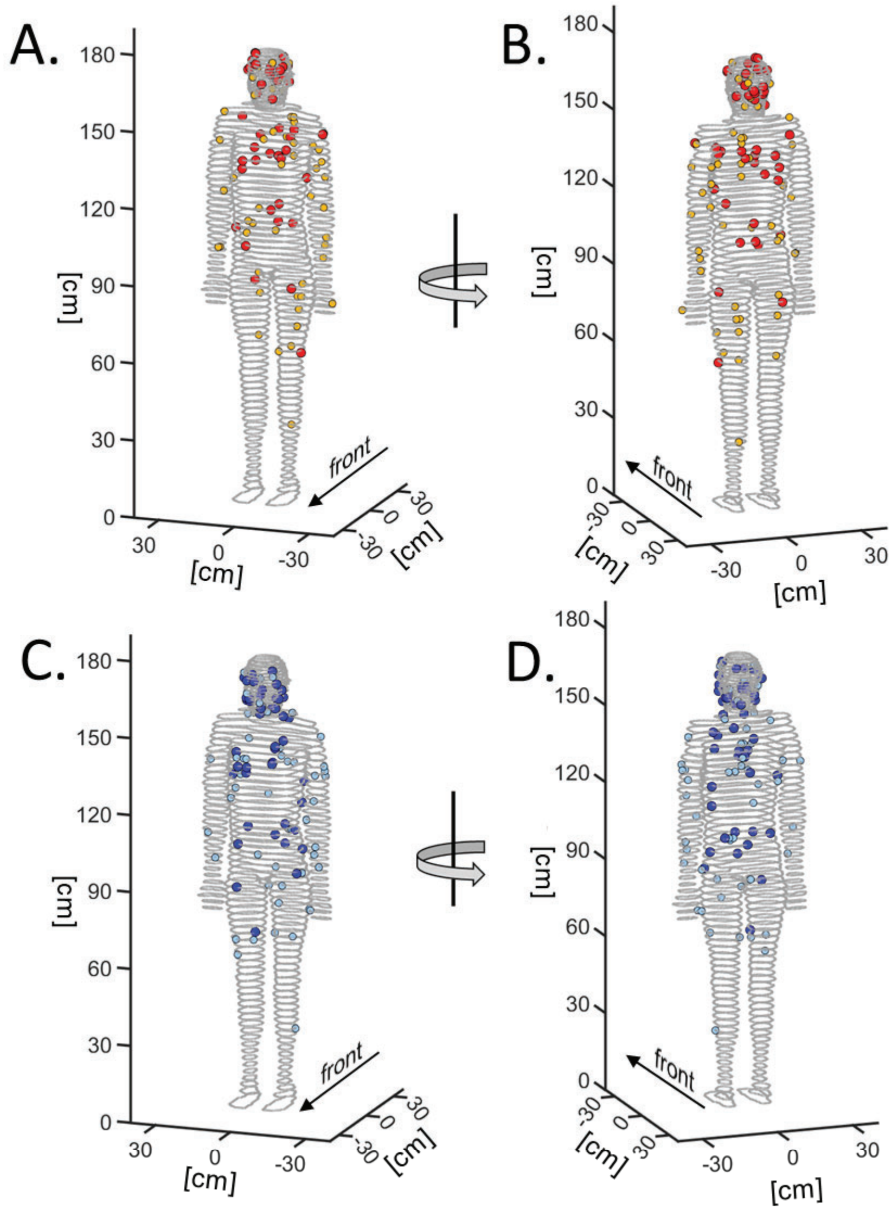

Figure 5. Entry (panel A-B) and exit (panel C-D) wounds projected onto a 3D human model. Panels A and C show the human model from a slightly elevated front side view, and panels B and D obliquely from behind. Larger, dark red and blue markers refer to lethal injuries.

Finally the position of the lethal entry wounds was identified (Figure 4 and 5), as these are important in terms of design of protection. Here, relatively large differences in distribution of locations compared to the more general wound distributions are found, Figures 2 and 3. First, the number of sub-regions that are involved in lethal shot lines are significantly lower than the number of regions involved in non-lethal shot lines. This concurs with intuition: lethal shot lines involve entry wounds in the head, neck, thorax, abdomen or pelvis. Only one entry wound (in the thigh) outside of those regions was considered lethal. This entry wound corresponded to a shot line almost parallel to the main standing axis of the person, resulting in injuries in the pelvic/abdominal areas.

Table 1. Localisation and lethality of the injuries in the dataset used for this study.

Localisation	No of wounds[1)] (N = 208)	Entry wounds (N = 104)	Lethal injury (N = 47)	Lethality[2)]
Head/neck	64	31	22	71 %
Thorax	58	29	17	59 %
Abdomen	26	12	5	42 %
Pelvis/buttocks	12	5	2	40 %
Extremities	48	27	1	4%

1) Here wounds are defined both as a physical entry or exit wound or a remaining bullet in the tissue.
2) Lethality = N(lethal injuries)/N(entry wounds)

3.2. Directionality analysis

For each pair of entry- and exit wounds an exact position in its assigned sub-region was randomly selected. This was done to introduce a slight variability of the precise localisation. The localisation of the entry and exit wounds projected onto the human model ComputerMan are shown in Figure 5. From these positions, a directionality for each shot line could be estimated, and are defined as follows: the projectile pathway starts at the entry and ends at the exit wound, and are assumed to be straight. Figure 6 shows all wound tracts, and the directionality are shown as arrows.

It is evident from Figure 6 that, in this data set, there are no obvious preferred direction to the shot lines, rather a seemingly random distribution of directions is observed. This was already indicated by the localisation distribution similarities between entrance and exit wounds (Figures 2 and 3). A question then arises: is this random distribution of directionality also a feature of the lethal wound tracts? To investigate this the directionality for the lethal wound tracts alone was plotted (Figure 7).

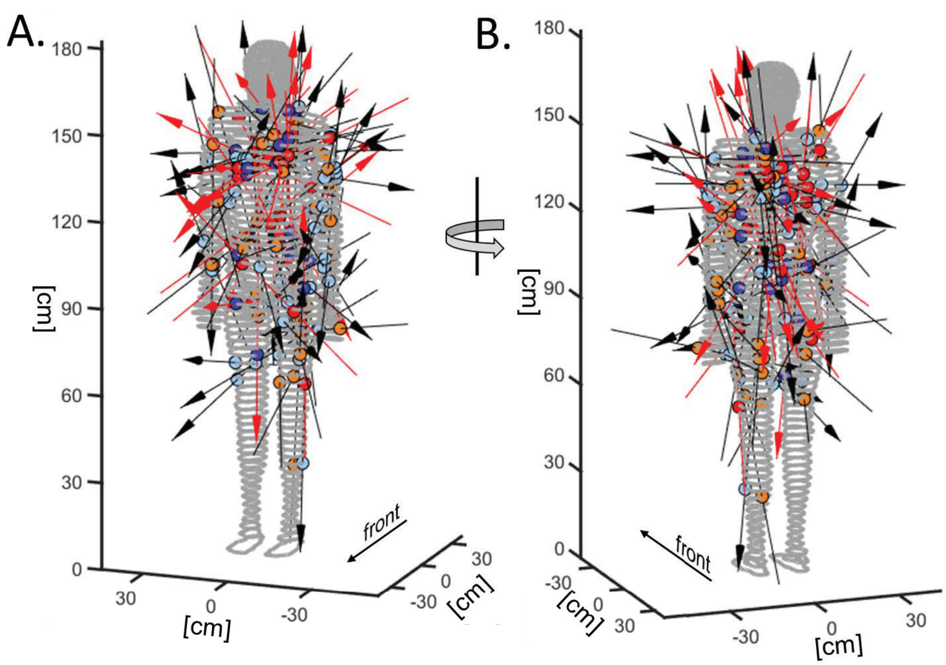

Figure 6. Directionality for all 104 shot lines. Each tract is defined by its corresponding entry and exit wound. An arrow shows the directionality, and indicates the direction of the projectile. The head injuries are removed for visibility reasons. Red arrows indicate wound tracts considered lethal; black non-lethal.

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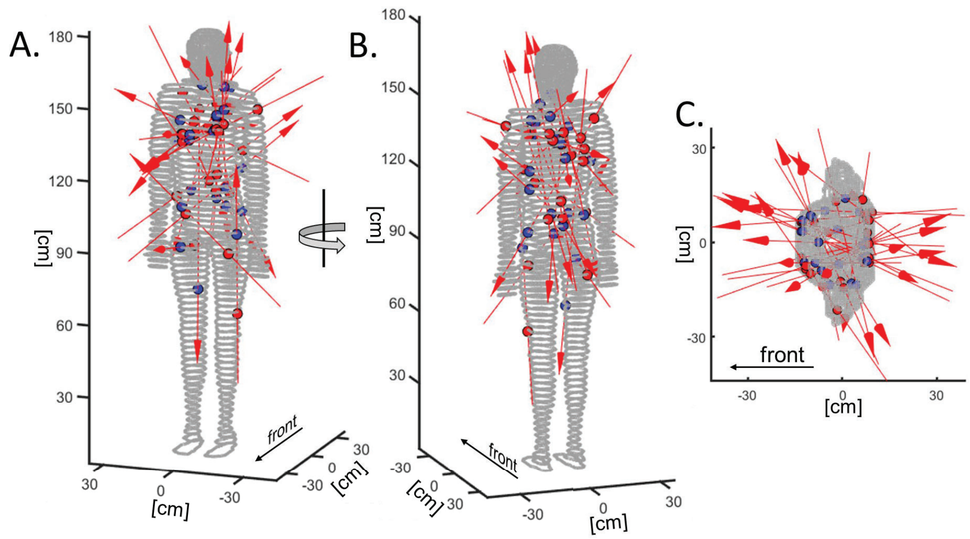

Figure 7. Directionality distribution for lethal wound tracts. The head injuries are removed for visibility reasons. The rightmost panel show the model directly from above.

Here, it is clear that the observed directionalities of the lethal wound tracts are more or less uniformly distributed along all directions. In fact, it appears that many of the wound tracts follow shot lines that does not overlap with the typical placement of hard body armour plates. Nonetheless, the full length of the lethal wound tracts outside the head are almost exclusively located within in the torso, with a preference to the thoracic area. This type of analysis is visually accessible and provides an illustration of the high degree of variability of the wound tracts from gun shots.

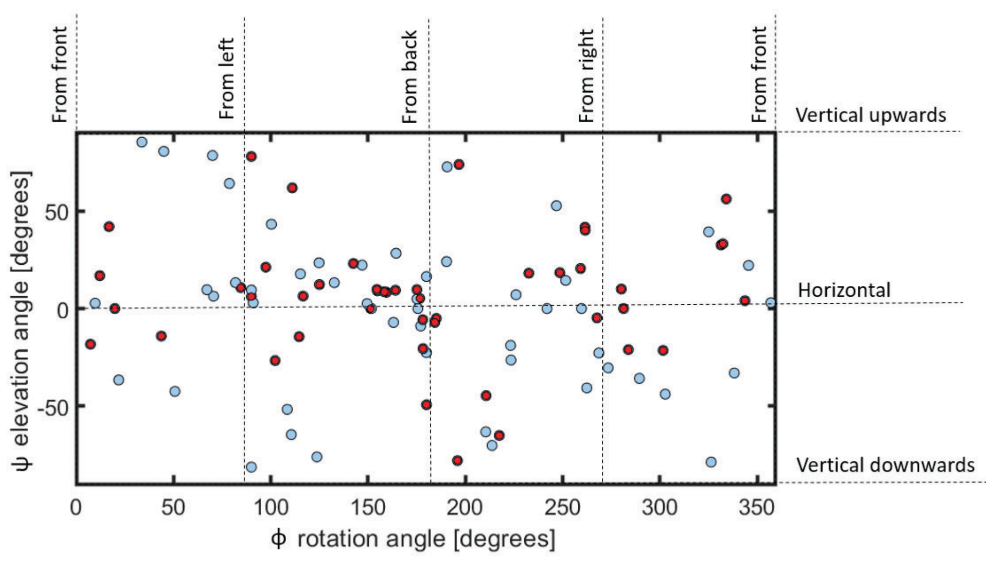

Figure 8. Angles φ, ψ (rotational and elevation angles) for each wound tract vector. Blue markers correspond to non-lethal injuries and red to injuries assessed as lethal.

In order to obtain a quantitative measure on the directionalities, each directionality vector was parametrised by its rotational angle around the human model's main axis as well as the elevation angle from the ground. The full-frontal direction was set to rotational angle $\varphi = 0°$, and a fully horizontal direction corresponds to an elevation angle $\psi = 0°$. Hence, a horizontal wound tract through the thorax directly from the front to the back, would be characterized by $\varphi, \psi = [0°, 0°]$. In Figure 8, the angles for all vectors are shown.

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Although the number of data points are too few to form a definitive conclusion about the directionality, it is noted that there seem to be a slight horizontal clustering of lethal shot lines. The variability in ψ is for lethal injuries ± 32°, while for non-lethal ± 38°. More data is however needed to ensure viable statistics.

4. CONCLUDING REMARKS

In this study we present a retrospective, morphologic characterisation of wound tracts from gun shots in Stockholm. All gun shots come from civilian shootings, i.e., suicide data as well as law enforcement shooting data has been omitted. The data set includes both wound tracts individually considered lethal and non-lethal. The lethal and non-lethal injuries are separated in the analysis and significant differences in the localisation and directionality is found.

Overall, the distribution of individual entry and exit wounds agree well with the data reported in the literature on civilian shootings. It is noted that while the lethal entry wounds are mainly located in the head, thoracic and abdominal region, the directionalities of the corresponding shot lines are more or less stochastic.

This method to analyse forensic data may serve as a basis to develop and optimize body armour, both soft and hard, plate armour.

References

[1] Liu, W. and Taylor, B., *The effect of body armor on saving officers' lives: An analysis using LEOKA data.* J Occup Environ Hyg, 2017. **14**(2): p. 73-80.

[2] Schram, B., et al., *The effects of body armour on mobility and postural control of police officers.* J Bodyw Mov Ther, 2020. **24**(3): p. 190-194.

[3] Larsen, B., Netto, K. and Aisbett, B., *The effect of body armor on performance, thermal stress, and exertion: a critical review.* Mil Med, 2011. **176**(11): p. 1265-73.

[4] Danielsson, U., Bergh, U. and Grambo, S., *Body armour. Effects on performance and physical load.* FOI, Totalförsvarets Forskningsinstitut, 2003. FOI-R--0799--SE.

[5] Dilday, J., et al., *Injury Patterns and Treatment Strategies in Civilian and Military Isolated Abdominal Gunshot Wounds.* World J Surg, 2023. **47**(11): p. 2635-2643.

[6] Mabry, R.L., et al., *United States Army Rangers in Somalia: an analysis of combat casualties on an urban battlefield.* J Trauma, 2000. **49**(3): p. 515-28; discussion 528-9.

[7] Bellamy, R.F., Maningas, P.A. and Vayer, J.S., *Epidemiology of trauma: military experience.* Ann Emerg Med, 1986. **15**(12): p. 1384-8.

[8] Marri, M.Z. and Bashir, M.Z., *An epidemiology of homicidal deaths due to rifled firearms in Peshawar Pakistan.* J Coll Physicians Surg Pak, 2010. **20**(2): p. 87-9.

[9] Nyberger, K., et al., *Epidemiology of firearm injuries in Sweden.* Eur J Trauma Emerg Surg, 2022. **48**(3): p. 2349-2357.

[10] Nyberger, K., et al., *Management and outcomes of firearm-related vascular injuries.* Scand J Trauma Resusc Emerg Med, 2023. **31**(1): p. 35.

[11] Thube, H.R. and Chikhalkar, B.G., *A study of fatal gunshot injuries over two years in Mumbai, India.* Indian Journal of Forensic and Community Medicine, 2017. **4**(3): p. 154-157.

[12] De-Giorgio, F., et al., *Suicidal or homicidal sharp force injuries? A review and critical analysis of the heterogeneity in the forensic literature.* J Forensic Sci, 2015. **60 Suppl 1**: p. S97-107.

[13] Jena, S., et al., *Critical Analysis of Firearm Wound Characteristics in Victims Brought for Autopsy at LHMC, New Delhi: A 20-Year Retrospective Study.* European Journal of Medical and Health Sciences, 2023. **5**(4).

[14] Myint, S., et al., *Fatal firearm injuries in autopsy cases at central Bangkok, Thailand: a 10-year retrospective study.* J Forensic Leg Med, 2014. **28**: p. 5-10.

[15] Solarino, B., Nicoletti, E.M. and Di Vella, G., *Fatal firearm wounds: a retrospective study in Bari (Italy) between 1988 and 2003.* Forensic Sci Int, 2007. **168**(2-3): p. 95-101.

[16] Toygar, M., et al., *An analysis of firearms-related deaths between 1993-2010: a retrospective study.* Ulus Travma Acil Cerrahi Derg, 2013. **19**(6): p. 536-42.

[17] Gill, J.R. and Pasquale-Styles, M., *Firearm Deaths by Law Enforcement.* Journal of Forensic Sciences, 2009. **54**(1): p. 185-188.

[18] Belmont, P.J., Jr., et al., *Incidence and epidemiology of combat injuries sustained during "the surge" portion of operation Iraqi Freedom by a U.S. Army brigade combat team.* J Trauma, 2010. **68**(1): p. 204-10.

[19] Rainio, J., Lalu, K. and Penttila, A., *Independent forensic autopsies in an armed conflict: investigation of the victims from Racak, Kosovo.* Forensic Sci Int, 2001. **116**(2-3): p. 171-85.

https://doi.org/10.52202/081621-0025

[20] US Army lab, *A Computer Man Anatomical Model*, 1978, Army ballistic research lab Aberdeen proving ground MD.