

Analysis of Injuries Sustained by Law Enforcement Officers Wearing Body Armour

D. Watts^{1,2}, MS, L. Alejandro de Leon, MD³, K. Inaba, MD⁴, FRCSC, FACS, and C. Bir, PhD¹

¹*Department of Biomedical Engineering, Wayne State University, 818 W. Hancock, Detroit, MI 48201, USA*

doriwatts@wayne.edu

²*Explico Engineering, 40028 Grand River Avenue, Suite 300, Novi, MI 48375*

³*Grady Memorial Hospital, 80 Jesse Hill Jr Drive, Atlanta, GA, 30303*

⁴*Department of Surgery, Keck School of Medicine, USC, Los Angeles, CA, USA*

Abstract. To further understand Behind Armor Blunt Trauma (BABT), a database of real-world cases has been established. Data were collected related to the threat, body armour worn at the time of the incident, armour penetration injury, and overall resulting injuries. A questionnaire was completed by participants describing their injuries and post-incident limitations. Medical records were obtained, when possible, including radiographic imaging results. A total of 101 cases were reviewed and characterized with the assistance of a trauma surgeon. Although the majority were minor injuries such as bruises, over 40 cases were considered clinically significant. These cases include rib and sternal fractures, pulmonary and hepatic contusions, hemothorax, pleural effusion, spleen laceration, and hemoperitoneum. A statistical analysis was performed to assess the relationship between variables related to the incident (i.e. vest level, weapon type, standoff distance) to variables related to injury (i.e. penetration injury status, internal injury status, maximum AIS (MAIS) score). Most cases resulted in injuries with a MAIS score of 1 (n=62). Penetration injuries were found in 13 cases, and internal injuries were not found in 8 of those 13 cases. Internal injuries were noted in 17.8% (n=18) of cases, with the shot location in 5 of the 18 cases being at the outer limit of the vest or an extremity. Vest level, standoff distance, and weapon type did not have significant relationships with whether or not there was a penetration injury, internal injury, or MAIS score. There was a notable (but not significant) relationship between vest level and clinical significance (P=0.011). Many cases resulting in MAIS scores of 2 or higher involved shots to areas not protected by armour. However, pulmonary contusions, small bowel wounds, and hepatic contusions occurred due to BABT. This data analysis improves understanding of vest performance in real-world scenarios, therefore providing information for the improvement of armour.

1. INTRODUCTION

Law enforcement officers (LEOs) are exposed to significant occupational hazards that result in both fatal and nonfatal injuries. Their job often requires physical engagement with suspects, vehicular operations, and exposure to environmental risks and they experience some of the highest rates of work-related injuries compared to other professions [1]. Between 2012 and 2017, over 300,000 LEOs were treated in emergency departments across the United States [2]. According to the most recent Law Enforcement Officers Killed and Assaulted (LEOKA) data, a total of 13.2% of all LEOs were assaulted in 2023 with 33.7% of these officers sustaining injuries [3]. In addition, there has been an increase in injuries related to assaults with firearms over the past ten years with the total going from 9.4% in 2014 to 13.8% in 2023 [3].

Body armour plays a crucial role in modern personal protection systems, safeguarding not only LEOs, but military personnel from ballistic threats. The design and effectiveness of body armor have evolved significantly over the years, incorporating advanced materials and structural innovations to enhance protection while maintaining wearability. However, despite these advancements, the phenomenon of behind armor blunt trauma (BABT) remains a critical concern given the energy transfer that can cause an injury even if the vest physically stops the bullet from penetrating. In addition, there are issues with body armour fit and coverage ([4]) that may also lead to officer injury based on a round not impacting the armour.

In an effort to determine the type of injuries sustained by LEOs in the field, a BABT database has been established [5]. The characterization and understanding of real-world BABT cases is helpful in establishing a link between armour use, threat level, and injury outcome. In addition, it can help to determine appropriate thresholds for certification standards. As such, Bir et al. (2017) published their findings regarding back face signature (BFS) assessment in a laboratory setting in an attempt to correlate the deformation into clay to known injuries that resulted from real-world cases. Results indicated a 50%

risk of severe injury with a deformation of 43.6 mm [5] which aligns with the current National Institute of Justice 0101.07 standard [6]. However, additional work to determine how real-world injuries correlate to the current certification standards is warranted.

In an effort to understand the types of real-world injuries being sustained by LEOs, the current research explores a dataset of medical outcomes related to BABT and penetrating trauma. Characterization of the injuries reported in medical records and self-reports are presented. In order to report trends in the incidence of injury in real-world scenarios where body armour was involved, 101 cases where officers were shot while wearing body armour were compiled and analyzed.

2. METHODOLOGY

Cases were identified from the IACP/DuPont Kevlar Survivor's Club database along with databases held by various body armor manufacturers. After the identification of potential cases, the officers were contacted, and consent was obtained. A survey was provided to each officers along with a request for their medical records. Whenever possible, police reports were also obtained. Key variables were extracted from the medical records by a level I trauma surgeon and from the police reports by trained researchers.

Data extracted from medical records for the analysis includes age, gender, vital signs, anatomical location of the gunshot, wound description, imaging studies, surgeries performed, and time spent in the hospital. Data extracted from police reports, surveys, and interviews for the analysis includes type of weapon used, type of vest worn, level of protection of the vest, and standoff distance. Injuries were coded according to the Abbreviated Injury Scale (AIS). A total of one hundred and one (101) cases had adequate data and were included in the analysis.

Data were analyzed using the Statistical Package for Social Science (SPSS), version 23 (SPSS INC., Chicago, IL). Two-sided Fisher's exact test was used to assess the relationships between variables to improve understanding in scenarios where officers are shot while wearing body armour.

3. RESULTS

3.1 Demographics

Regarding the officers and their vests, of the 101 cases analyzed, 98 (97.0%) involved officers that were male and 3 (3.0%) that were female. The average age was 34.45 +/- 7.36 years. The most common armour noted in the dataset were level II armour (32 or 31.7% of cases) and level IIIA armour (20 or 19.8% of cases) (Table 1). The level of enhanced protection was unknown for a large majority of cases (n=87 or 86.1% of cases).

Regarding incident information, the most common standoff distance was 0 to 5 feet (1.5 m) (n=35, or 34.7% of cases). The second-most common standoff distance was 6-10 feet (1.8-3 m)(n=22, or 21.8% of cases), and the distance was unknown for 23 or 22.8% of cases (Figure 1). The most common weapon type noted was handgun (n=65, or 64.4% of cases), followed by shotgun (n=11, or 10.9% of cases) (Figure 2). The most common type of firearm used (of the cases in which the specific firearm was known) was a 9mm (n=18). Cases involving a single shot made up a majority of the cases (n=55, or 54.5% of cases) and there were 46 cases that involved multiple shots. The most common case within the multiple shots category was 2 shots (n=38, or 37.6% of cases). The most common type of bullet noted was lead (n=15), but a for a majority of cases, the bullet type was unknown (n=62, or 61.4% of cases).

Table 1. Gender, age, and vest level demographics.

Gender			
Male	98	97.0%	
Female	3	3.0%	
Age			
Mean	34.45		
Standard Deviation	7.355		
Min	22		
Max	53		
Vest Level			
Unknown	27	26.7%	
IIA	16	15.8%	
II	32	31.7%	
IIIA	20	19.8%	
III	5	5.0%	
IV	1	1.0%	

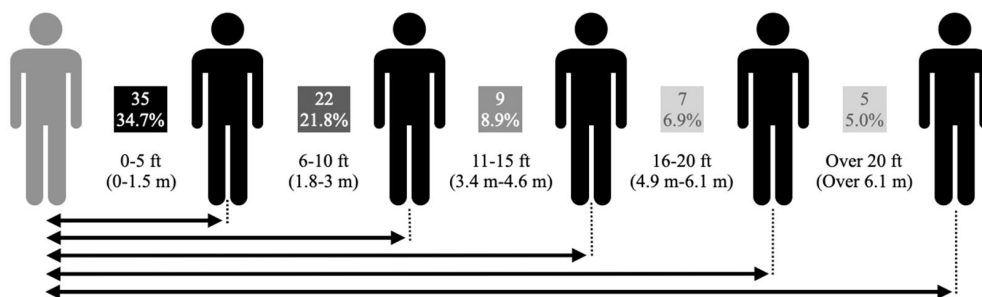


Figure 1. Standoff distances noted in the dataset.

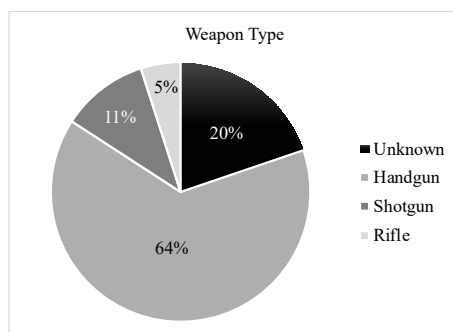


Figure 2. Weapon types observed in the dataset.

3.2 Injury Outcomes

Regarding injury and clinical outcome, 43 cases (42.6%) were found to be clinically significant. Internal injuries, which were defined as any injury within a cavity that did not include skin or soft tissue, were found in 18 cases (17.8%). The types and number of internal injuries thereof are reported in **Error! Reference source not found.** Penetration injuries were noted in 13 cases (12.9%). Note – these injuries include those that are considered backface signature injuries where the bullet is stopped by the vest but there is still an open wound behind the armour. Of the 82 cases in which the patient disposition was known, 45 patients (44.6%) were sent home, and 37 patients (36.6%) were admitted. The mean hospital length of stay was 2.76 days. In 59 cases (58.5%), the hospital length of stay was noted as 0 days or 1 day.

All 101 officers had at least 1 external injury, 56 (55.4%) had at least 2 external injuries, 24 (23.8%) had at least 3 external injuries, and 9 (8.9%) had at least 4 external injuries. Of the 78 officers who underwent some form of imaging, 36.6% (n=37) received positive findings which included fractures of the rib and clavicle, bullets and/or bullet fragments, hemothorax, and pulmonary contusion. A total of 27 officers (26.7%) underwent some form of surgical procedure. Regarding AIS scores, a majority of cases

resulted in injuries with an MAIS score of 1 (n=62, or 61.4%) (**Error! Reference source not found.**). Shot locations are provided in Figure 4 with injuries coded with a maximum AIS of 2, 3, or 4.

To determine if there was a statistically significant association between the variables of Internal Injury, Single vs Multiple Shots, Vest Level, Max AIS Score and Clinical Significance, a two-sided Fisher's exact test was conducted. The variables of Max AIS had a significant association with all variables examined except Vest Level. There was also a statistically significant association between Single Shot vs Multiple Shot and Clinical Significance (Table 3).

Table 2. Types of internal injuries reported.

Internal Injury Reported	# Cases
Spleen laceration	1
Hemoperitoneum	1
Grade II liver injury - Hepatic contusion	1
Pleural effusion	1
Retroperitoneal hematoma	1
Sternal fracture/hematoma	1
Hemothorax	1
Pneumothorax	1
Pulmonary vein rupture	1
Rib fractures	3
Lower extremity artery/muscle tear/severe fracture/ injury	2
Severe facial fractures/injuries	2
Upper extremity artery/muscle tear/severe fracture/ injury	3
Small bowel/colon/intestine laceration	4
Pulmonary contusion	5

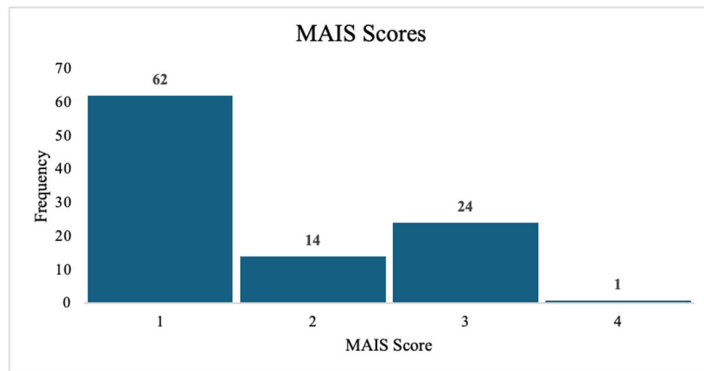


Figure 3. AIS score histogram.

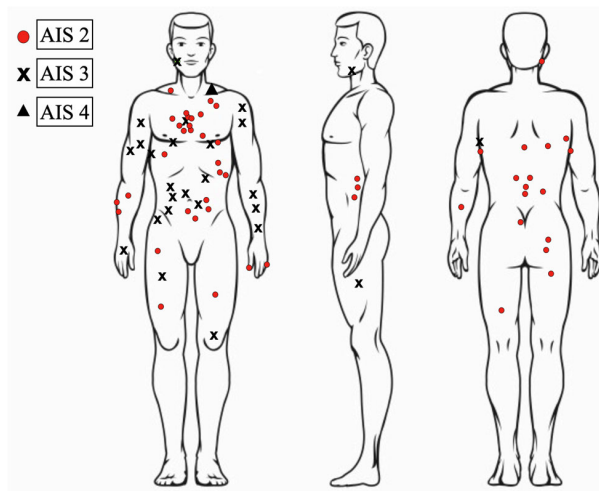


Figure 4. Shot locations of cases that had injuries that were categorized as AIS 2, 3, or 4.

Table 3. P values resulting from the two-sided Fischer’s exact test.

	Internal Injury	Single Shot v Multiple Shots	Vest Level	Max AIS Score	Clinical Significance	P Values
						P < 0.001
						0.05 < P < 0.001
						0.1 < P < 0.05
						0.2 < P < 0.1
						P > 0.2
Internal Injury		0.049	0.447	<0.001	<0.001	
Single Shot v Multiple Shots	0.049		0.628	<0.001	<0.001	
Vest Level	0.447	0.628		0.446	0.011	
Max AIS Score	<0.001	<0.001	0.446		<0.001	
Clinical Significance	<0.001	<0.001	0.011	<0.001		

3.3 AIS 2 Injuries

Fourteen of the 101 total cases documented injuries that had a maximum AIS score of 2. Half of the cases were determined to be clinically significant, and the other half not clinically significant (n=7 for each category). Cases 2, 11, 38, 44, 58, 84, and 95 were clinically significant.

Case 2 involved an officer wearing a Level II vest who was shot once with a .40 caliber handgun at a distance of approximately 10 feet (3 m). He was diagnosed with rib fractures to the left 8th and 9th ribs, a spleen laceration, and hemoperitoneum. Case 11 involved an officer wearing a Level II vest who was shot once with a 9 mm handgun at a distance of approximately 5 feet (1.5 m). He had a deep abrasion and laceration to his left chest inferior to the nipple, and was diagnosed with a fracture of the left 8th rib with a small effusion. Case 38 involved an officer wearing a Level II vest who was shot twice with an unknown weapon at a distance of approximately 8 feet (2.4 m). He reportedly had small contusions to the upper right chest, a large contusion to lower right back, and was diagnosed with a pulmonary contusion. The officer indicated he believed he was shot 2 to 3 times in the same spot in his back. Case 44 involved an officer who was shot twice with a .45 caliber handgun at an unknown distance wearing a vest of an unknown level. The injuries involved the left shoulder and left flank, and injuries included a left clavicle fracture and a bruise to the epigastrium area.

Case 58 involved an officer wearing a Level II vest who was shot once in the shoulder with a .40 caliber handgun at an unknown distance. Multiple foreign bodies were found in his shoulder, which required debridement and removal of the foreign bodies. Case 84 involved an officer wearing a Level IIIA vest who was shot once with a .22 caliber weapon at a distance of approximately 6 to 10 feet (1.8 to 3 m). He had a contusion on his back and soft tissue damage to the right hip. A pelvis X-ray indicated an L3 fracture. Case 95 involved an officer wearing a Level III vest who was shot four (4) times with a .45 caliber pistol at a distance of approximately ten (10) feet (3 m). Two of the shots impacted the armour in the area of his chest, which resulted in severe bruises, but records indicated the right arm was “blown away” and needed to be completely reconstructed, and his left arm required an elbow arthroscopy with bullet removal.

Case 2 (described above) was the only MAIS2 case that was coded as a penetration injury. Four cases were coded as having an internal injury (Cases 2, 18, 38, and 86), which included diagnoses of a splenic laceration, a pulmonary contusion, and a sternal fracture, respectively. Case 18 involved an officer wearing a level II vest who was shot once in the chest from a distance of two (2) feet (0.6 m). He had a large abrasion to the left chest and a pulmonary contusion. Case 86 involved an officer wearing a level IIIA vest who was shot twice in the chest with a .25 caliber handgun at a distance of 6 to 10 feet (1.8 to 3 m). He presented with a bruise to the left side of his chest from one shot and was diagnosed with a sternal fracture as a result of the 2nd shot, which reportedly missed the vest and struck the sternal notch.

Cases 19, 58, and 95 required surgical procedures, all to extremities. Case 19 involved an open reduction and internal fixation (ORIF) on the 5th metacarpal, Case 58 (described above) required debridement and removal of foreign bodies in the shoulder, and Case 95 (described above) required a left elbow arthroscopy with bullet removal.

Table 4. Circumstances surrounding AIS 2 injuries sustained by officers.

STUDY	Armor Type	Threat	Standoff Distance	Anatomical Structures Injured
2	Level II	.40	6 - 10 feet (1.8-3 m)	Skin defect, hemoperitoneum, 8th and 9th left rib fractures, grade I spleen laceration
4	Level II	9 mm	0 - 5 feet 0-1.5 m	Abrasion, entrance wound at the right axilla area, exit wound inferiolateral to the right scapula
11	Level II	9 mm	0 - 5 feet 0-1.5 m	Left chest deep abrasion and laceration, small effusion, left 8th rib fracture
18	Level II	Unknown	0 - 5 feet 0-1.5 m	Large abrasion to left chest, pulmonary contusion in anterior lower left lobe
19	Unknown	Unknown	Unknown	Left 5th metacarpal fracture
27	Unknown	.45	Unknown	Severe bruise and laceration to right abdomen that turned necrotic
33	Level IIIA	Handgun	0 - 5 feet 0-1.5 m	Commuted fracture to right mastoid air cells without intracranial injury, and chest abrasion
38	Level II	Unknown	6 - 10 feet (1.8-3 m)	Contusions to right upper chest and right lower back, right lower lobe pulmonary contusion
44	Unknown	.45	Unknown	Left clavicle fracture, bruise in epigastrium, left flank abrasion
58	Level II	.40	Unknown	Multiple foreign bodies in left shoulder with skin defect above the clavicle without bleeding
84	Level IIIA	.22	6 - 10 feet (1.8-3 m)	Back contusion, L3 fracture, and soft tissue damage in the hip
86	Level IIIA	.25	6 - 10 feet (1.8-3 m)	Chest bruise and sternal fracture
95	Level III	.45	6 - 10 feet (1.8-3 m)	Right arm "blown away" and needed to be completely reconstructed, bruises to center of chest
101	Level IIA	.40	0 - 5 feet 0-1.5 m	Left pectoral muscle tear

In summary, of the 14 cases that had injuries with an MAIS score of 2, five of the cases involved shots to areas not covered by the vest; one case was to the axilla (Case 4), and four were to an extremity (Cases 19, 33, 58, and 95). Four of the cases involved an internal injury (Cases 2, 18, 38, and 86).

3.4 AIS 3 Injuries

Twenty-four cases of the analyzed 101 cases involved injuries with a MAIS score of 3 (Table 5). Twenty-one of the 24 were clinically significant. Cases 1, 21, and 34 were found to not be clinically significant.

Case 10 involved an officer wearing who was shot twice with a shotgun at a distance of approximately 15 feet (4.6 m). The left abdomen and left thigh were affected areas, with the left flank sustaining multiple entrance wounds (specifically the left costal area) and the left thigh sustaining a wound to the lateral portion. Internal injuries to the small bowel, superficial stomach, and mesocolon were sustained and required suture repair. Case 15 involved an officer wearing a Level II vest who was shot twice (once in the chest and once in the left forearm) at a distance of approximately 17 feet (5.2 m). The chest sustained an abrasion, and the proximal left forearm sustained extensive soft tissue disruption and required surgical repair of ulnar artery and forearm muscles. This officer also sustained a hepatic contusion.

Case 22 involved an officer wearing a Level IIA vest who was shot twice with a handgun at a distance of approximately 5 feet (1.5 m). This officer was shot in the chest and left upper extremity; he sustained a 4 cm contusion on his right chest above and medial to the nipple, and a through-and-through injury to his wrist, which shattered the distal end of the radius, requiring an ORIF surgery. Case 24 involved an officer wearing a Level IIIA vest who was shot four times with a handgun at a distance of approximately 13 feet (4 m). This officer was shot in the anterior chest, knee, and sacrum. The chest impact resulted in a bruise, and the knee sustained a through-and-through injury. The right thigh below the buttock

was another reported area of injury. This officer sustained an iliac wing fracture with bullet fragment lodged just to the right of his sacrum and also required knee surgery.

Case 35 involved an officer wearing a Level IIA vest who was shot twice with a shotgun at a distance of 5 feet (1.5 m) in his right chest. The chest wound involved a severe laceration and a large right anterior superior pulmonary contusion. Case 36 involved an officer wearing a Level II vest who was shot six times with a pistol at a reported distance of 15 feet (4.6 m). The injured regions included the left shoulder, back, right hand and right thigh. The officer diagrammed two shots to the back of the vest, and reported injuries included erythema and penetration to the skin at the L2-L3 level. A foreign body was noted lateral to the pelvis. The left humerus sustained a comminuted fracture, and his right hand sustained a through-and-through wound, which resulted in a comminuted fracture of metacarpal heads 4 and 5. The open fractures required surgery. This officer did not sustain an internal injury of the thorax.

Case 40 involved an officer who was shot twice with a shotgun at a distance of 2 feet (0.6 m). A contusion was noted in the sternal area, a right humerus fracture was noted as well as a left shoulder injury with a deformity, and an internal injury to the popliteal artery and vein was noted, as there was reportedly no pulse in the right popliteal vasculature. Surgical procedures were required for fractures and a vascular graft. Case 41 involved an officer who was shot twice with a shotgun at a distance of 10 feet (3 m). The back and the left forearm were the reported areas affected. The officer was reportedly diagnosed with left forearm compartment syndrome, which included a radial fracture and required a fasciotomy. Case 42 involved an officer who was shot twice with a 9 mm handgun at a distance of 8 feet (2.4 m). This officer sustained lacerations to their left ear and scalp, and injuries to the right buttock, right forearm, and left lower abdomen. The officer was diagnosed with L5 and sacral fractures, as well as colon and small bowel injuries. Case 43 involved an officer who was shot twice with a rifle at a distance of 20 feet (6.1 m). The right shoulder, right posterior chest, and left flank were affected. Chest and pelvis x-rays revealed multiple bullet fragments and a right rib fracture. The humerus was fractured which required an ORIF surgery.

Case 45 involved an officer who was shot twice with a .45 caliber weapon at a distance of 5 feet (1.5 m). The affected areas were listed as mid-abdomen, upper left chest, right back, left superior limb, and right buttock. A chest x-ray revealed right hemothorax, and an ORIF surgery was required on the forearm. Case 46 involved an officer who was shot twice with a handgun at a range of 5 feet (1.5 m). The officer presented with abdominal pain and a pulseless left arm, with injury regions being noted as left neck, upper chest, left arm, and inferior limb. Imaging revealed bullet fragments in the chest region, as well as a left kidney laceration and left hand fracture. Case 50 involved an officer who was shot once with a 9mm handgun at a distance of approximately 3 feet (0.9 m). The affected area was noted as under the right armpit, where there was a hole. A bullet was found in this officer's intercostal space of the 11th rib above the diaphragm. The officer was also diagnosed with a liver contusion.

Case 54 involved an officer wearing a level IIIA vest who was shot seven times with a rifle at a distance of approximately 21 to 50 feet (6.4 to 15.2 m). Three of the shots were to the torso and abdomen, which resulted in severe bruising and a laceration. A six inch section of intestine needed to be removed as a result of the abdominal impact. There was also a through-and-through injury to the right bicep-triceps area and a grazing wound to the rear scalp. Case 59 involved an officer who was shot two times at point blank range with a 12-gauge shotgun. The chest, left eye, and right forearm were affected. The left eye injury required a skin graft and vitrectomy. The chest was noted as having a bruise. Case 60 involved an officer wearing a level IIA vest who was shot once with a 12-gauge shotgun at a distance of approximately 6 feet (1.8 m). In addition to burns, this officer sustained serious thoracic injuries due to a shot location under the left armpit that stuck the edge of the armor. This officer was reportedly diagnosed with a shattered lateral rib, a collapsed left lung, broken left shoulder girdle, and two ruptured deep pulmonary veins. Depending on the degree of the pneumothorax, this injury could potentially be an AIS 4 injury.

Case 69 involved an officer wearing a Level IIA vest who was shot twice with a .38 caliber weapon at a distance of 1 to 5 feet (0.3 to 1.5 m). The neck, chest, abdomen, and wrist were noted as affected areas. The operative findings reportedly pertained to the small bowel and colon, which indicated this officer had an internal injury. Case 71 involved an officer wearing a Level II vest who was shot twice with a .40 caliber weapon. This officer sustained a face abrasion, chest bruise, and an abdominal penetrating injury. A pelvis x-ray revealed a bullet in the abdominal cavity, and the officer was diagnosed with a retroperitoneal hematoma. Case 76 involved an officer wearing a level IV vest who was shot once with a 9mm weapon. The impact area was noted as the right lower quadrant, and operative findings indicated a comminuted left iliac wing fracture and a large left retroperitoneal hematoma.

Case 77 involved an officer wearing a Level II vest who was shot twice with a .38 caliber weapon at a distance of one foot. This officer reportedly had a bruised chest as well as lost soft tissue in the face, which had bone fractures and required multiple surgeries. This officer was also noticed to have an internal injury. Case 93 involved an officer wearing a Level II vest who was shot once with a .44 caliber weapon in her left chest below the breast at a distance of approximately 2 feet (0.6 m). This officer sustained a pulmonary contusion and broken ribs, as well as a ½” hole in the skin and extensive bruising. The officer was also diagnosed with pleural effusion.

Table 5. Circumstances surrounding AIS 3 injuries sustained by officers.

STUDY	Armour Type	Threat	Standoff Distance	Anatomical Structures Injured
1	Level II	Unknown	11 - 20 feet 3.4 m-6.1 m	Severe bruise to the right side of chest, below and inside of nipple, and 2 holes above left knee
10	Unknown	Shotgun	11 - 15 feet 3.4 m-4.6 m	Multiple left flank entrance wounds, small bowel, superficial stomach, and mesocolon wounds, and left lateral thigh wound
15	Level II	Unknown	16 - 20 feet 4.9 m-6.1 m	Chest abrasion, hepatic contusion, injury to ulnar artery and forearm muscles that required surgery
21	Unknown	Unknown	Unknown	Highly comminuted left mandible fracture, superficial bruises to the 3 shots that impacted the vest, and shots to the right buttock and left thigh
22	Level IIA	Handgun	0 - 5 feet 0-1.5 m	Through-and-through injury to wrist, resulting in comminuted fracture to distal end of radius, which required ORIF, and chest contusion
24	Level IIIA	Handgun	11 - 15 feet 3.4 m-4.6 m	Through-and-through injury to left knee with a laceration below the patella, resulting in knee surgery, iliac wing fracture with bullet fragment, and chest contusion
34	Level II	Unknown	11 - 15 feet 3.4 m-4.6 m	Through-and-through injury to the right humerus, extensively comminuted fracture to proximal humerus resulting in ORIF, abrasion to chest
35	Level IIA	Shotgun	0 - 5 feet 0-1.5 m	Large anterior superior pulmonary contusion with open wound from chest injury
36	Level II	Pistol	11 - 15 feet 3.4 m-4.6 m	Through and through injury to right hand, comminuted fracture to humerus and metacarpal heads 4 and 5, two gunshot wounds lateral to the spinal column between L2 & L3 with erythema and penetration to the skin and minimal bleeding, right thigh injury
40	Unknown	Shotgun	0 - 5 feet 0-1.5 m	Contusion in sternum, right humerus fracture, right thigh injury with injury to popliteal artery and vein - no pulses
41	Unknown	Shotgun	6 - 10 feet (1.8-3 m)	Left forearm compartment syndrome, radial fracture, fasciotomy left forearm
42	Unknown	9 mm	6 - 10 feet (1.8-3 m)	L5 fracture, transverse colon and small bowel injuries, ear and scalp lacerations
43	Unknown	Rifle	20 feet (6.1 m) and over	Right rib fracture, humerus injury resulting in ORIF
45	Unknown	.45	0 - 5 feet 0-1.5 m	Right hemothorax, right forearm injury resulting in ORIF
46	Unknown	.380	0 - 5 feet 0-1.5 m	Left arm injury resulting in pulselessness, left kidney laceration, left hand fracture
50	Unknown	9 mm	0 - 5 feet 0-1.5 m	Liver contusion, hole in right axilla
54	Level IIIA	Rifle	20 feet (6.1 m) and over	Abdominal injury requiring 6 inches of intestine removal, through-and-through injury to right arm, bruises and lacerations in area covered by armour
59	Unknown	12-Gauge Shotgun	Unknown	Left eye laceration requiring a skin graft, chest bruise
60	Level IIA	12-Gauge Shotgun	6 - 10 feet (1.8-3 m)	Lateral rib shattered, left lung collapse, 2 deep pulmonary veins ruptured, left shoulder gurdle broken
69	Level II	.38	0 - 5 feet 0-1.5 m	Small bowel and colon injuries
71	Level IIA	.40	Unknown	Face abrasion, chest bruise, abdominal penetrating injury, retroperitoneal hematoma
76	Level IV	9 mm	Unknown	Small bowel and colon injuries
77	Level IIIA	.38	0 - 5 feet 0-1.5 m	Bruised chest, facial bone fractures and lost tissue resulting in multiple surgeries
93	Level II	0.44	0 - 5 feet 0-1.5 m	Extensive left chest bruising with large ulcerations, pleural effusion, rib fractures, and lung contusion

In 13 of the 24 cases that had injuries with an MAIS score of 3, the injury that resulted in the MAIS 3 score involved shots to areas not covered by the vest; one case was to the axilla (Case 50), and twelve were to an extremity (Cases 1, 15, 21, 22, 24, 34, 36, 40, 41, 46, 59, and 77). Twelve of the cases (50%) involved an internal injury (Cases 10, 15, 35, 40, 54, 59, 60, 69, 71, 76, 77, and 93).

3.5 AIS 4 Injury

There was one case with a MAIS 4 injury. The officer was wearing a Level IIIA vest and was shot twice with a .38 caliber weapon from 20 feet (6.1 m); one shot was to zone 1 of the neck (**Figure 5**), and one was to the pectoral region of the chest. The injury to the chest was listed as a bruise. The operative findings stated left subclavian artery and venous injuries (Figure 5). The hospital length of stay was 5 days, and the case was considered clinically significant.

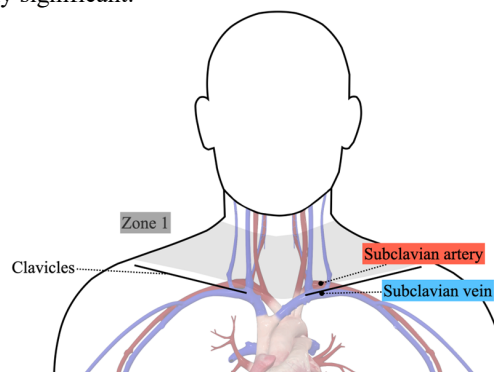


Figure 5. Description of the anatomy involved in the injury from Case 73, MAIS 4.

4. DISCUSSION AND CONCLUSION

The relationships between scenario variables and injuries have been described, and a thorough explanation of the cases resulting in MAIS 2, 3, and 4 injuries has been provided, as well as a breakdown of the internal injuries observed and shot locations with relation to the armour. Vest level, standoff distance, and weapon type did not have significant relationships with whether or not there was a penetration injury, internal injury, or MAIS score. There was a notable (but not significant) relationship between vest level and clinical significance ($P=0.011$) and internal injury and single shot versus multiple shot scenarios ($P=0.049$) (Table 3). Not surprisingly, there was a significant relationship between MAIS score and internal injury and clinical significance and internal injury ($P<0.001$ for both). There was also a significant relationship between MAIS score and single shots versus multiple shots and also clinical significance and single shot versus multiple shots ($P<0.001$ for both), suggesting that officers who are impacted more than once have a higher rate of sustaining more serious injuries.

A majority of the shot locations (61%) fell within the bounds of the generally covered armour area. However, as is shown in Figure 4, a considerable number of shots resulting in MAIS 2+ injuries (approximately 39, or 46%) fell outside or at the edge of the region that would be protected by body armour. Many AIS 3 injuries were the result of shots to the extremities that caused extensive vascular damage. The AIS 4 injury was a shot to region 1 of the neck (i.e. on the edge of the area covered and protected by armour). With regards to the shot locations of AIS 2+ injuries (Figure 4), one injury was to the eye and required a skin graft, but the shot locations appeared to be on the vest; the eye injury was a potential secondary injury.

There are several considerations when examining whether a vest offers the best protection, both coverage and fit are essential. One of the complaints related specific to body armor is the lack of mobility and comfort of the vest. Making the vest as small as possible will often add to the comfort level, however this ultimately would decrease the protective ability of the armor. Modifications by the officer to how the vest is worn in the field can also lead to areas of poor coverage. The current data support the need to ensure proper coverage to avoid life threatening injuries. This analysis shows that when shots impact armour, the resulting injury is minor a majority of the time (i.e. AIS level 1).

Even with shots on the armour, serious injuries still occurred as a result of behind armour blunt trauma without penetration. Internal injuries noted that were not coded as penetration injuries (i.e. BAPT injuries) included pulmonary contusion (Cases 18, 35, and 38), small bowel injury, superficial stomach wound, and mesocolon wound (Cases 10 and 69), and hepatic contusion (Case 15). AIS 2 injuries that were not coded as internal or penetrating injuries included a lumbar vertebrae fracture (Case 84), muscle tear (Case 101), rib fracture (Case 11), clavicle fracture (Case 44), and substantial hematoma (Case 27). All AIS 3 injuries that were not coded as internal or penetrating injuries were injuries to the extremities or were shots to areas not covered by armor (i.e. axilla). The only AIS 4 injury in the dataset was the result of an impact to an area not covered by the body armour.

It is notable that many of the cases (n=62) that resulted in minor injuries (MAIS score of 1) such as bruises and abrasions despite the serious circumstances of the threat. Twenty-one (33.9%) of the MAIS 1 cases had standoff distances in the range of 0 to 5 feet (1.5 m), and 14 (22.6%) had standoff distances in the 6 to 10 feet (1.8 to 3 m) range.

The discussed analysis of the dataset of 101 documented incidents provides insight into the injuries sustained by officers in the field. However, a limitation of analyzing any event in hindsight is the available data. In the subject analysis, police reports, interviews, medical records, photographs, and other documents were relied upon. Unfortunately, very few cases contained all the data required to fully reconstruct and understand the incident and injuries. The analysis was performed with the data obtained to the most reasonable extent possible. Another aspect of this analysis is that it only included LEOs that survived their injuries, the analysis of those who sustained fatal injuries is ongoing. Even given these limitations, the current effort provides insight into real-world injuries sustained by officers wearing armour which can be used to compliment both experimental and laboratory testing.

Acknowledgements

Kathryn Loftis for assisting with AIS coding.

References

Ballistic Resistance of Body Armor NIJ Standard 0101.07.

- [1] H. M. Tiesman, D. I. Swedler, S. Konda, and K. M. Pollack, "Fatal occupational injuries among U.S. law enforcement officers: A comparison of national surveillance systems," *Am. J. Ind. Med.*, vol. 56, no. 6, pp. 693–700, Jun. 2013, doi: 10.1002/ajim.22182.
- [2] H. M. Tiesman, S. Konda, J. Grieco, M. Gwilliam, J. Rojek, and B. Montgomery, "Resistance-Related Injuries Among Law Enforcement Officers: Addressing the Empirical Gap," *Am. J. Prev. Med.*, vol. 59, no. 6, pp. e231–e238, Dec. 2020, doi: 10.1016/j.amepre.2020.05.015.
- [3] United States Federal Bureau of Investigation, "Law Enforcement Officers Killed and Assaulted (LEOKA)." 2023. Accessed: Mar. 13, 2025. [<https://cde.ucr.cjis.gov/LATEST/webapp/#>]. Available: <https://cde.ucr.cjis.gov/LATEST/webapp/#>
- [4] C. Bir, "US Body Armor Fit and Coverage," Final Report TSWG Task PP-IP-4206. Contract Number: N4175619C3033, 2022.
- [5] C. Bir, R. Lance, S. Stojisih-Sherman, and J. Cavanaugh, "Behind Armor Blunt Trauma: Recreation of Field Cases for the Assessment of Backface Signature Testing," in *30th International Symposium on Ballistics*, DEStech Publications, Inc., Dec. 2017. doi: 10.12783/ballistics2017/16912.
- [6] "Ballistic Resistance of Body Armor NIJ Standard 0101.07," Oct. 2023.