Spring 2023

Design of Force Indicator for Ballistic Armor Trauma Pad

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Final Report for MECE:461 and MECE: 497 Honors Senior Design

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Fall 2022 – Spring 2023

Project No. 14

Abstract

The purpose of the Force Indicator for Ballistic Armor Vests is to obtain an approximate value for the impact a bullet delivers through a trauma pad after the Kevlar layer stops the initial bullet. This approximation will be applied in the field to assist in medical treatment of gunshot wounds. The indicator is made from a pressure-sensitive film located behind the Kevlar layer and trauma pad, and it can be easily removed in the field for examination. The impact vest and force indicator are self-contained for ease of implementation. The device will be tested with 9mm, .22 Long Rifle, and .357 Magnum ammunition to visualize the differences in impact pressure between different bullet calibers. This result will be used to create a device by which injuries resulting from the impact of a bullet can be predicted, as well as to verify this device's functionality in testing.

Contents

1. Introduction

The need for a Force Indicator was presented to the group by Dr. Jon Gerhardt with American Engineering Group (AEG). This Force Indicator will be used to measure the impact transferred through the trauma pad to the user of the ballistic vest. The Force Indicator will also be able to show where the trauma may have occurred to the user after being shot. The purpose of the project is to create a visual indicator to diagnose injuries from a gunshot with a ballistic vest more quickly, which could save the life of the wearer. Contained in this report is the design process, final design, testing methods and results, bill of materials, costs and sources, and conclusions.

Constraints were given by Dr. Gerhardt and Abraham Panikottu to give a better scope of what the project needed to achieve. The force indicator needed to be sleek, light, relatively low cost, and integrated into the previous group's trauma pad. In particular, the device needs to be designed with female police officers in mind, and not be made in a way that makes wearing a ballistic vest any more cumbersome. The final deliverable is a working prototype having undergone testing.

2 Design

During the design process, the group performed research of the effects of ballistic impact on a body, mainly in the relation between gunshot trauma and broken ribs, ruptured organs, etc. The group also researched the work completed by the previous group to learn more about the project and the fabrication and testing methods used. Knowing the general issue at hand, the group brainstormed possible mechanisms that would allow for the recording of this impact force behind the trauma pad.

After initial research, a few existing mechanisms were determined: electronic sensors, impression material, ink-based shock sensors, and pressure sensitive film. For these designs, several parameters were considered, including cost, safety, additional weight and ease of use and fabrication. Based on these constraints, the pressure sensitive film was chosen as the best option. This mechanism adds very little weight or bulk to an existing ballistic impact vest trauma pad when compared to electronics or impression material. It will have a lower cost and will be easier to use in practice than an electronic device and will be simpler to manufacture than the ink-based system.

One of the key benefits of the pressure sensitive film is its ease of reading when utilized by medical professionals; no special tools are needed to determine if their patient has potentially life-threatening injuries. Use of electricity is not relied on, eliminating a power source that might be compromised after being jarred by a ballistic impact. It is unlikely for the film to have a shelf-life acting as a limiting factor on cost or continuing utility, as it doesn't rely on batteries or ink to remain chemically sound. However, the film will need to be replaced after being read if color change occurs; this would likely happen alongside a damaged vest, so replacing the pressure sensitive film is not a major concern.

Based on these, the group determined the best method of utilizing this film in the device would be a double-sided approach to record the impact itself with a variety that records at a lower range of pressures, and a side that operates at a higher range of pressures to show the point one might expect broken bones or ruptured organs. With an overlaid display chart on a clear plastic sheet, the affected areas would be easy to see, and with hook-and-loop attachment points on the film case, the device itself can be easily taken off when checking on a patient, as well as easily affixed when integrating the trauma pad into the ballistic vest. Previous tests allowed for an unscathed portion of the previous trauma pad that is still available for testing. While reprinting of the trauma pad was considered, resin was not able to be budgeted for the level of testing needed for the team to complete the prototype.

2.1 Force Indicator

The visual force indicator consisted of two pressure-sensitive films. The first layer is a more sensitive indicator ("LLW", rated for 71-355 psi); this will show the exact point of impact of the bullet. The second layer is of a less sensitive ("MS", rated for 1,420-7,110 psi) and will be used for medical purposes. This will allow doctors to predict injury when treating police officers and the like in the field.

2.1.1 Medical Application

The first layer of film is of a low sensitivity, known as "MS", accurately showing the pressure imparted on the victim by the bullet. This colored marking can be used to identify potentially severe injuries, including ruptured organs, internal bleeding, and broken bones.

2.1.2 Gunshot Application

The second layer of pressure-sensitive film is higher in sensitivity than the medical side, known as "LLW", and shows the location of the bullet's impact in a less detailed way. This will show the location of impact and will serve as a general reference in the case a bullet impact does not do enough to show pressure applied to the medical side, or visual signs of injury on the victim.

2.2 Casing

Inside the casing is the pressure sensitive film, which is the main component of the force indicator. This is attached via hook-and-loop at the rear of the impact vest for easy detachment in the field. Within the fabric case, additional hook-and-loop allows the case itself to be fastened closed.

2.2.1 Identification Sheet

The casing of the apparatus includes a thin, clear plastic sheet of 30-gauge vinyl material through which the film can be viewed. For the medical professional to align the impacts with major organs and bones, an outline is painted via stencil on the clear sheet to offer a better understanding of what has been affected by an impact.

2.2.2 Fabric Case with Connectors

The casing itself is bound on the edges with thick, water repellent, polyester type material to prevent sweat from getting into the device and impacting its effectiveness. On this fabric border strip, hook-and-loop fasteners are attached so that the indicator apparatus can be easily attached and de-attached from the trauma pad. Additionally, a label noting the probability of an injury or impact is present on the bottom of the indicator, so confusion is lesser amongst medical professionals.

2.3 Standards and Codes

As engineers, there is an emphasis on working under certain “best practices.” These are what are known as standards and codes. While standards and codes are not often required by law, they ensure that projects follow a certain level of consistency or reliability that often promote efficient practices, safety of consumers, and accountability for the engineers responsible. In this project, the group must work within the guidelines set by AEG; this means following applicable standards and codes so that the design is consistent, reliable, and safe.

While not strictly in the field of engineering, certain legal requirements should be considered in the design process. Relevant codes and standards for this design project include NIJ armor performance standards, ITAR rules and regulations, and laws restricting the sale and use of body armor, including bans on possession of body armor by convicted felons.

The National Institute of Justice, or NIJ, standard classifies equipment by levels of ballistic performance and tests armor for performance and compliance with minimum standards. This includes categories for ballistic resistance from a firearm and stab resistance from a knife. For the purposes of the project, the group is conducting testing on bulletproof vests rated at an NIJ rating of ‘IIIA’, which means that the vest should be able to survive bullets up to a .44 Magnum, a very powerful round. The device created by the group should in no way impede this protection rating; the whole assembly should still be able to pass the testing imposed by the NIJ.

Bulletproof vests are (to different extents) legally restricted items, both in a domestic and international market. ITAR is an international treaty that prohibits the international sale of body armor and bulletproof vests. If this force indicator was to be sold as an assembly with a bulletproof vest and trauma pad, it would not be allowed to be sold internationally. 18 US Code 931 bans the purchase, ownership, and possession of body armor by convicted felons. For this design to be included with a bulletproof vest, background checks would be required to prevent the armor from being sold to felons. As a result, this project must account for these legal restrictions.

3. Design Verification

To prove the validity of a force indication system, the group simulated the environment the device would be used in. Being that the indicator would be used in tandem with ballistic armor to assist medical professionals in the diagnosis of injuries, it was prudent to recreate injury using ballistic impact. The previous group investigated the use of ball bearing testing, but ended up using practical testing, which most closely mimics the true environment. With this, the group decided to use live firearms to test ballistic armor with the device.

3.1 Ballistic Testing

The ballistic impact pad was tested with impacts from 3 calibers of ammunition: .22LR, 9mm and .357 Magnum. The group expected to see different magnitudes of pressure imparted on the force indicator during each test. These calibers were chosen given the NIJ standards for IIIA body armor (the highest rating for soft armor as is common with police), which should expect to stop all calibers in use during testing.

The standard testing procedure for the first round mimicked the method the previous design group used; a flexible bulletproof panel at the desired rating (IIIA) was placed in front of the trauma pad to stand in as a bulletproof vest, and the force indicator apparatus was placed behind the trauma pad with two 11”x11”x5.5” clay block backstops (typically used in impact testing). During the first test, for each caliber, two shots were taken from approximately 5 meters away to show the pattern it creates on the indicator. The film sample will be swapped out after each test to allow for fresh samples to be inserted into the casing. To determine the utility of the trauma pad, the pad was removed for an additional shot with .357 magnum.

For a second round of testing, a second armor panel was used, since the first panel was deformed to a large degree due to the number of bullets it had caught. Additionally, the group received clearance at this point from Dr. Gerhardt to test the device using the larger sheets of Prescale pressure film, rather than the small samples previously used. In contrast to the previous test, this test served as verification of the final concept using these larger sheets of film. To show the differences between different possible scenarios, shots were taken with differing calibers, as well as with and without the trauma pad; this allowed the group to see more drastic indications for analysis.

Each test was performed in a safe environment at a monitored shooting range, in this case, in the ROTC shooting range in South Schrank Hall; use of these facilities required the group to work around the schedules of other groups on campus but allowed for testing regardless of weather. A range safety officer was present to ensure that proper safety protocols were followed during the testing procedure. During shooting, there is typically only ricocheting fragments expected when firing on a hard surface, such as steel. Due to the soft nature of ballistic armor (which typically catches fragments), no shield is needed during testing, especially due to the moderate distance of 5 meters. With that said, shooting is an inherently dangerous activity; any material can send fragments flying if hit with a bullet.

3.1.1 .22LR Testing

For the first phase of testing, a rifle of barrel length 20” fired a .22LR caliber lead round nose 40 grain bullet. Per calculations, the group estimated a kinetic energy from the following equation, using standard values:

$$KE=\tfrac{1}{2}mv^2$$

$$m = 36\ grains \times 1kg/15430\ grains = 0.00233276kg$$

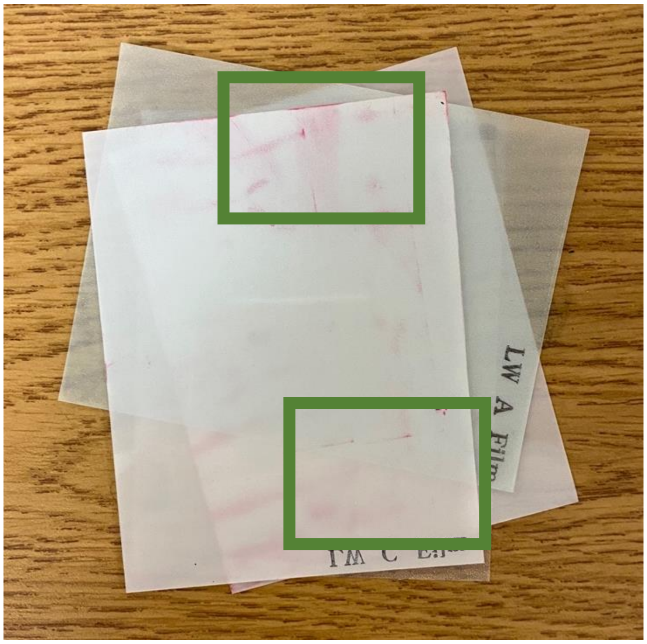
$$V = 1070ft/s \times 1m/s/3.281ft/s = 326.136m/s$$

$$KE=\tfrac{1}{2} \times 0.00233276kg \times (326.136m/s)^2 = 124.058J$$

$$KE = 124.058J \times 1ft\ lb/1.356J = 91.501ft\ lbs$$

Bullet		**.22LR**	
	Min	**Max**	**Standard**
Mass (grains)	20	60	36
Velocity (ft/s)	575	1,750	1,070
Kinetic Energy (ft lbs)	14.680	553.088	91.501

This served as the smallest expected impact on the pressure film, as it has the lowest kinetic energy. During testing, the .22LR bullet left the least noticeable impact when the trauma pad was used, as was in line with the group’s predictions. The following impacts were recorded, as shown in a green box:



.22LR Film Samples After Initial Tests

3.1.2 9mm Testing

For the second phase of testing, a pistol of barrel length 4” fired a 9mm caliber full-metal jacket 115 grain bullet. Per calculations, the group estimated a kinetic energy from the following equation, using standard values:

$$KE=\frac{1}{2}mv^2$$

$$m = 115 \text{ grains} \times 1\text{kg}/15430 \text{ grains} = 0.00745187\text{kg}$$

$$V = 1175\text{ft/s} \times 1\text{m/s}/3.281\text{ft/s} = 358.146\text{m/s}$$

$$KE=\frac{1}{2} \times 0.00745187\text{kg} \times (358.146\text{m/s})^2 = 477.904\text{J}$$

$$KE = 477.904\text{J} \times 1\text{ft lb}/1.356\text{J} = 352.484\text{ft lbs}$$

Bullet	**9mm**		
	Min	**Max**	**Standard**
Mass (grains)	115	147	115
Velocity (ft/s)	951	1,444	1,175
Kinetic Energy (ft lbs)	230.900	680.484	352.484

This served as a middle-level expected impact on the pressure film, as it had a larger kinetic energy than the .22LR. During testing, the impact left was slightly more noticeable, leaving an almost wave-like pattern on the pressure film. This spoke more to a general impact and less towards a broken bone. The testing impacts are shown below, outlined in green boxes for clarity:

9mm Film Samples After Initial Tests

3.1.3 .357 Magnum Testing

For the third phase of testing, a revolver of barrel length 4" fired a .357 magnum caliber semi-jacketed soft point 158 grain bullet. Per calculations, the group estimated a kinetic energy from the following equation, using standard values:

$$KE=\frac{1}{2}mv^2$$

$$m = 140$$

$$grains \times 1kg/15430\ grains = 0.00907185kg$$

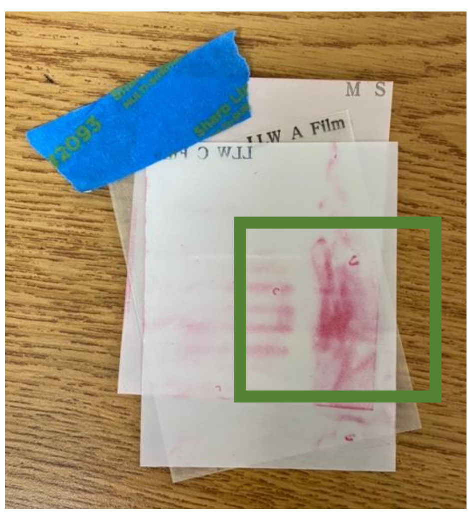
$$V = 1350ft/s \times 1m/s/3.281ft/s = 411.48m/s$$

$$KE=\frac{1}{2} \times 0.00907185kg \times (411.48m/s)^2 = 768.048J$$

$$KE = 477.904J \times 1ft\ lb/1.356J = 566.483ft\ lbs$$

Bullet	.357 Magnum		
	Min	Max	Standard
Mass (grains)	125	158	140
Velocity (ft/s)	1,235	1,360	1,350
Kinetic Energy (ft lbs)	423.257	648.784	566.483

This served as the largest expected impact on the pressure film, due to it having the highest kinetic energy. As such, this caliber was utilized for more extensive testing, both with and without the presence of the trauma pad for illustrative purposes. When using the trauma pad, impact was severely mitigated during initial testing. Impact is noticeable using the film, as is shown below and outlined in a green box:



.357 Magnum Film Samples After Initial Tests

Without the pad, the damage appeared as though it had been substantial, despite the armor panel catching the bullet, as was evident by the large deformation present in the ballistic clay and large marker on the pressure film. In the below, the film sample can be seen as it was during testing, within the force indicator sleeve; the black and red markings represent organs and skeletal structures. To see the sleeve on its own, refer to Appendix C.

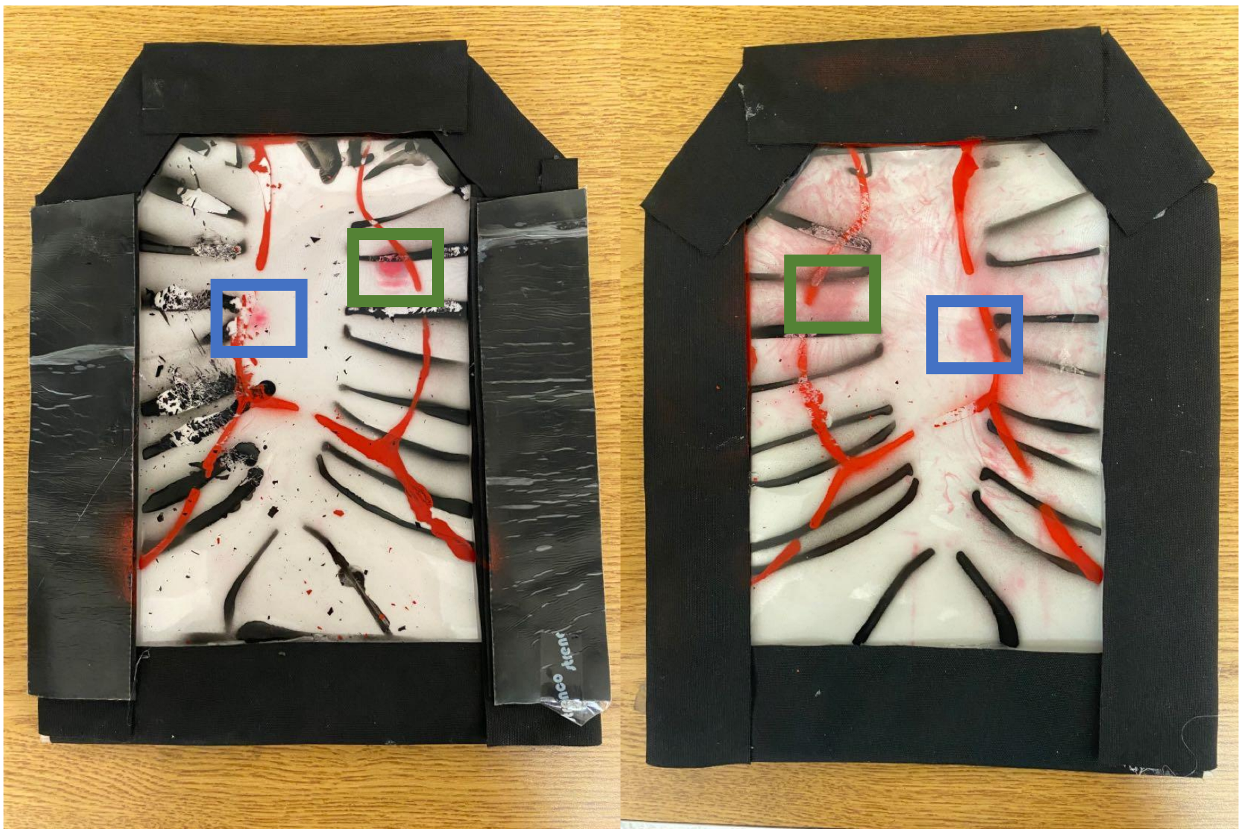
Post .357 Magnum Test (No Trauma Pad) – Impact Is Very Visible on Sample (Left Side of Clear Vinyl)

3.1.4 Verification Testing

A second round of testing was completed in order to verify that the final assembly of film sheets would be able to work as intended. For this test, a new armor panel was used, since the first panel was extremely damaged after initial testing; all other elements of testing are the same as the previous round, including clay backing. Full sheets of film were used for this test, with the group having settled on “MS” for the injury side, and LLW for the indication side. Having inserted the full 10”x12” sheets of MS and “LLW” Prescale films into the indicator sleeve, four shots are fired to demonstrate the greatest variety of possible situations the design might be used in.

The first shot was a .22LR, with the trauma pad present in front of the indicator device. This was followed by a second shot of the same bullet, this time with no trauma pad. Initial observations of these shots show that while there is a minor indication on the “LLW” sheet, there is no presence of red on the “MS” sheet. This was in line with what was to be expected, since .22LR is not an especially powerful round.

This process is repeated, instead using .357 Magnum to give a large contrast to the previous .22LR shots. As expected, the rounds left a large 'webs' of red on the "LLW" sheet, with dime sized dark red marks on the "MS" sheet. This demonstrates that not only is the indicator aware of an impact, it can say with relative certainty that the rib is broken and further medical treatment would be required, meeting the starting objective of the group. Below, the results are demonstrated; the marks in the green box are from testing using the trauma pad, while the marks in the blue box are from testing without the trauma pad.



"MS" – Injury Side *"LLW" – Indication Side*

During the verification testing, the group analyzed shots taken on the film. The two shots are shown to cause injury on the "MS" side as demonstrated by marks found on the upper right and lower left side of the 'heart'. The corresponding indication 'webs' are found on the upper right and lower right sides of the 'heart' on the "LLW" film.

Noting one of the impacts made by .357 Magnum to be darker and clearer than the other on the "MS" film, the group realized that the darker mark was made when using the trauma pad; this seems to suggest that the trauma pad contributes to more injury, rather than less, as was previously hoped. While backface deformation may have been minimal in tests of the trauma pad's effectiveness, it cannot be ascertained whether it is harmful to a user. This does not impact the effectiveness of the force indicator, but it does open the possibility of redesign for the trauma pad.

4. Costs

4.1 Bill of Materials

Part	Quantity	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
Trauma Pad	1 Each	Previous Honors Research Group	N/A	N/A	N/A
Flexible Ballistic Armor Panel Level IIIA	2 Panels	Battle Steel	$59.98	N/A	$120.80
30 Gauge Vinyl Sheeting (54" Width)	3 Yards	MarineVinylFabric.com	N/A	$32.38	$71.11
600D Polyester Fabric	2 Yards	Big Duck Canvas	N/A	$22.40	$33.62
Black and Red Acrylic Spray Paint	1 Can, Each	Krylon	N/A	N/A	$0, already own
LRN .22LR	1 Box of 50 rounds	Aguila	$10	N/A	$10
FMJ 9mm	1 Box of 50 rounds	Remington	$21	N/A	$21
SJSP .357 Magnum	1 Box of 50 rounds	Magtech	$45	N/A	$62.01
Prescale Pressure Film Samples	2 Sheets	Fujifilm	N/A	N/A	$0, samples
2" Hook and Loop Strips w/ Adhesive Back	1 Pair of Rolls	Strenco	$13.02	N/A	$13.02
2" Hook and Loop Strips w/o Adhesive Back	1 Pair of Rolls	Myuren	$13.95	N/A	$15.71
Prescale MS Film Sheet	1 Single Ply Sheet	Fujifilm	$55	N/A	$55
Prescale LLW Film Sheet	1 Double Ply Sheet	Fujifilm	$60	N/A	$74.28
Roma Plastalina Ballistic Clay	2 Blocks	Chavant	$17.85	N/A	$45.65
Total					**$522.20**

The previous design group created a trauma pad as the final deliverable of their project; the force indicator will be attached to this prototype for testing purposes. After discussion with Aaron Trexler, who works with the 3D printing program at the University of Akron, it was determined that no resin exists from the previous group. Relaying that information to Dr. Gerhardt with AEG, the group determined it was more cost-effective to reuse the existing trauma pad rather than purchasing additional resin for the purpose of reprinting. Hence, the original trauma pad is included on the bill of materials. Additionally, the previous group's testing did not leave behind a usable ballistic panel for use in the current project, so the same panel was repurchased for use in testing.

During the construction of the prototype, the group utilized spray paint and stencils to ensure the clear vinyl sheeting is properly marked with the location of major organs and bones. These materials were provided by the group as art supplies already in possession of the members, thus they incurred no additional cost to the project. Additionally, sewing, while initially considered for assembly, was not utilized, and did not incur a cost during construction. With that said, the group constructed it using hot glue, again provided by members at no cost to the project.

4.2 Labor

The group was the sole laborer involved in designing, fabricating, and testing the prototype. This incurred no cost other than the time commitment to the project, but estimates can be made as below that are representative of a real world commission:

3 *team members* * 4 *hrs/week* * 30 *weeks* * $40/*hr* = $14,400 *total*

5. Conclusion

5.1 Accomplishments

The group has successfully designed and tested the force indicator prototype. After testing the prototype with three different caliber bullets, the group was able to see a difference in results. The .22 LR showed the least amount of impact, the .357 Magnum showed the most amount of impact, and the 9mm sat in the middle. These results were expected, and it showed a positive result for the group's prototype. Also, the force indicator was successfully integrated into the previous group's trauma pad, which was one of the project goals. It was very light weight and small, adding no unnecessary discomfort to the user. Lastly, the group was able to identify the location of impact as well as an estimated force transferred through the trauma pad. Overall, the indicator design was very successful.

5.2 Uncertainties

Uncertainty in testing may come from a variety of factors. These include the exact thickness and properties of materials at each point on the vest and accuracy of mathematical modeling for the magnitude of force reaching the indicator through the vest. Ballistics is a very complex field. When a ballistic impact occurs, the bullet might travel at a different speed or impact at a different angle than expected; even two bullets will deform in different ways when contacting a surface. Not everything can be accounted for in practice, but the testing performed in this design process would represent a reasonable environment, since only a 'broad strokes' approach is needed to diagnose something like a broken rib in the field.

5.3 Ethical considerations

The device will be used to prevent injury or save the life of a victim of gunshot trauma; hence, there are many ethical considerations. During testing, firearms were loaded and fired at the device. Safety is paramount in this environment, so only individuals experienced in the safe handling of firearms performed the testing procedure. Additionally, this testing occurred at a well-maintained and staffed shooting range with safety glasses and hearing protection. This testing was necessary to analyze scenarios that the device would face when worn behind trauma pads.

Creation of any device in the realm of body armor must be scrutinized as an engineer. Body armor comes with its own set of laws and regulations, especially with regards to criminals being able to possess any type. This is a fair rule, as dangerous people shouldn't be able to make themselves more dangerous as an aid to illegal behavior. However, in this case, the device would be most useful to someone trained in medical practices and is just as likely to be dangerous in the hands of a criminal as a tourniquet or other medical devices. To further boost the ethical value of such a product, it is likely to help identify serious injuries in the field when used by police, soldiers, and civilians so treatment can begin immediately.

In terms of sustainability, this product does not have a great outlook for reusability. Being that it is not beneficial to use again after a ballistic impact, due to the color change inherent in the design, it would likely be thrown away and replaced. However, shootings are not necessarily common enough for this to cause the issue of crowding landfills. In combination with the fact that the main consumable piece to this product is the film, which constitutes an inexpensive, low volume item, there is not a major concern for its impact as a whole.

While this device itself does not interact with a bulletproof vest in a way that could compromise the bullet-stopping capabilities, it is necessary that the device be installed so it remains that way. Additionally, one would hope for a lack of false positive results where it seems like trauma has occurred when it hasn't will be important; accurately defining the visual scale will be important, and standards of manufacturing should be held constant.

5.4 Future work

The next step that could be taken with this project is integrating similar systems onto hard body armor, possibly with a system that makes the plates themselves change color, although this would be on the cutting-edge of metallurgy and materials science.

It should be noted that the discovery that arose during the second round of testing, wherein the use of the previous group's trauma pad seemed to produce more impact, suggests that further work should be conducted to improve the trauma pad itself. This is outside the scope of designing an indicator and does not reflect the inability of the indicator in identifying the location of impact or a possible injury.

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Appendix A Ammunition Specifications

Muzzle Velocity @ 1100 fps for Item 24K

Range (Yards)	Velocity (Ft/Sec)	Energy (Ft/Lbs)	Bullet Path (inches)	Bullet Path (1 MoA)	Wind Drift (inches)	Wind Drift (1 MoA)	Time of Flight (Seconds)
0	1100.0	335.8	-0.75	0.0	0.0	0.0	0.0000
25	**1056.2**	**309.6**	**0.0**	**0.0**	**0.25**	**1.0**	**0.0696**
50	1019.1	288.2	-1.2	-2.3	0.98	1.9	0.1419
75	986.8	270.2	-4.48	-5.7	2.15	2.7	0.2168
100	958.1	254.8	-10.0	-9.5	3.73	3.6	0.2939
125	932.3	241.2	-17.88	-13.7	5.7	4.4	0.3733
150	908.6	229.1	-28.26	-18.0	8.04	5.1	0.4548
175	886.6	218.2	-41.28	-22.5	10.75	5.9	0.5384
200	866.1	208.2	-57.05	-27.2	13.82	6.6	0.6240
225	846.8	199.0	-75.73	-32.1	17.24	7.3	0.7116
250	828.4	190.4	-97.43	-37.2	21.01	8.0	0.8012
275	810.8	182.4	-122.3	-42.5	25.12	8.7	0.8927
300	793.9	174.9	-150.48	-47.9	29.58	9.4	0.9863
325	777.6	167.8	-182.11	-53.5	34.39	10.1	1.0818
350	761.9	161.1	-217.33	-59.3	39.56	10.8	1.1793
375	746.8	154.8	-256.31	-65.3	45.08	11.5	1.2788
400	732.0	148.7	-299.19	-71.4	50.95	12.2	1.3804
425	717.8	143.0	-346.13	-77.8	57.19	12.9	1.4840
450	703.9	137.5	-397.3	-84.3	63.8	13.5	1.5897
475	690.3	132.2	-452.87	-91.0	70.77	14.2	1.6976
500	677.1	127.2	-513.02	-98.0	78.12	14.9	1.8075
525	664.3	122.4	-577.93	-105.1	85.86	15.6	1.9197
550	651.7	117.9	-647.8	-112.5	93.99	16.3	2.0340
575	639.4	113.4	-722.81	-120.0	102.51	17.0	2.1506
600	627.3	109.2	-803.18	-127.8	111.44	17.7	2.2696

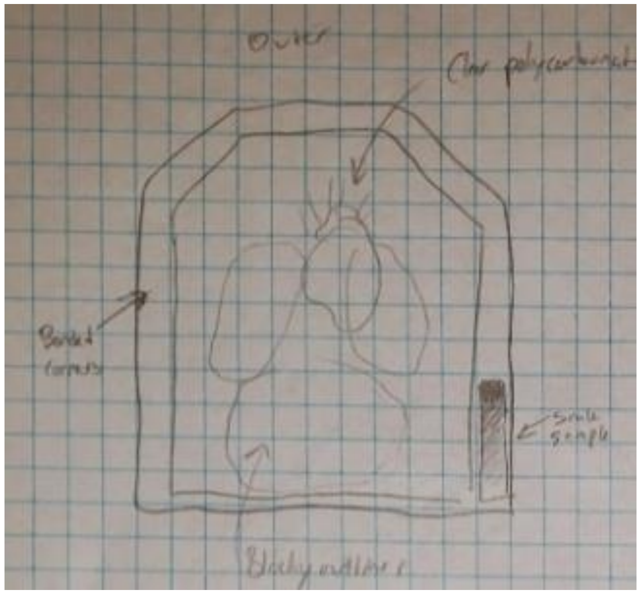
(Retrieved from buffalobore.com)

22 Long Rifle (.22LR):

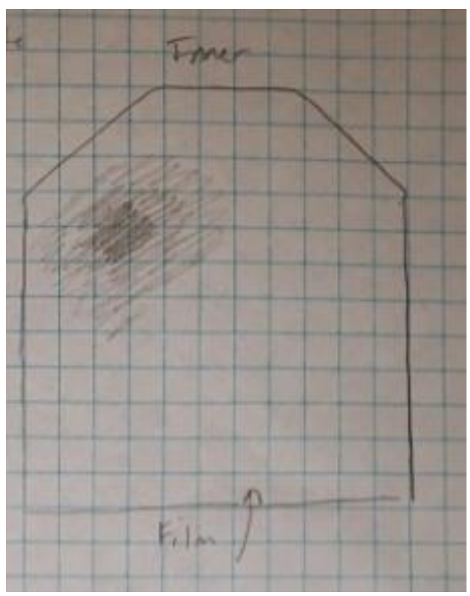
Rimfire Rifle Cartridge / Cartridge Manufacturer / Load Identity	Bullet Weight Grains	Bullet Ballistic Coefficient	Muzzle Velocity Fps.	100 Yds. Velocity Fps.	200 Yds. Velocity Fps.	Muzzle Energy Ft. lbs.	100 Yds. Energy Ft. lbs.	200 Yds. Energy Ft. lbs.	Rifle Zero 50 Yds.	Bullet Drop 75 Yds.	Bullet Drop 100 Yds.	Bullet Drop 150 Yds.	Bullet Drop 200 Yds.
.22LR / (C) / Mini Mag	36	.126	1,260	1003	874	127	80	61	0	- 1.8"	- 5.6"	- 19.9"	- 44.1"
.22LR / (C) / Stinger	32	.084	1,640	1,065	857	191	81	52	0	- 1.1"	- 3.8"	- 15.2"	- 36.4"
.22LR / (C) / Velocitor	40	.126	1,435	1,084	921	183	104	75	0	- 1.3"	- 4.3"	- 15.9"	- 36.4"
.22LR / (R) / C-Bee	33	.084	740	637	550	40	30	22	0	- 6.0"	- 17.0"	- 55.4"	- 118.6"
.22LR / (R) / Cyclone	36	.125	1,280	1010	878	131	82	62	0	- 1.8"	- 5.5"	- 19.4"	- 43.4"
.22LR / (R) / Game Load	36	.125	1,280	1010	878	131	82	62	0	- 1.8"	- 5.5"	- 19.4"	- 43.4"
.22LR / (R) / Golden Bulet	40	.139	1,255	1016	892	140	92	71	0	- 1.8"	- 5.5"	- 19.5"	- 43.1"
.22LR / (R) / Golden Bullet	36	.125	1,280	1010	878	131	82	62	0	- 1.8"	- 5.5"	- 19.4"	- 43.4"
.22LR / (R) / Golden Bullet	29	.106	1,095	903	789	77	53	40	0	- 2.5"	- 7.5"	- 25.7"	- 56.1"
.22LR / (R) / Sub Sonic	38	.125	1,050	901	803	93	68	54	0	- 2.7"	- 7.8"	- 26.4"	- 57.0"
.22LR / (R) / Target	40	.149	1,150	975	872	117	84	67	0	- 2.1"	- 6.4"	- 22.0"	- 47.8"
.22LR / (R) / Thunderbolt	40	.139	1,255	1016	892	140	92	71	0	- 1.8"	- 5.5"	- 19.5"	- 43.1"
.22LR / (R) / Viper	36	.117	1,410	1055	896	159	89	64	0	- 1.4"	- 4.6"	- 16.9"	- 38.6"
.22LR / (R) / Yellow Jacket	33	.107	1,500	1075	895	165	85	59	0	- 1.2"	- 4.1"	- 15.7"	- 36.6"
.22LR / (W) / X22LRSUBA	40	.138	1,065	920	826	101	75	61	0	- 2.5"	- 7.5"	- 25.3"	- 54.5"
.22LR / (W) / XT22LR	40	.148	1,150	974	870	117	84	67	0	- 2.1"	- 6.4"	- 22.0"	- 47.9"
.22LR / (W) / WD22LRB	40	.148	1,150	974	870	117	84	67	0	- 2.1"	- 6.4"	- 22.0"	- 47.9"
.22LR / (W) / WW22LR	40	.138	1,255	1,015	891	140	91	71	0	- 1.8"	- 5.5"	- 19.5"	- 43.1"
.22LR / (W) / X22LRPP	40	.117	1,280	998	863	146	89	66	0	- 1.8"	- 5.6"	- 19.9"	- 44.4"
.22LR / (W) / XT22LRS1	40	.138	1,300	1,036	904	150	95	73	0	- 1.6"	- 5.1"	- 18.4"	- 41.0"
.22LR / (W) / X22LRH	37	.128	1,280	1,014	883	135	84	64	0	- 1.7"	- 5.4"	- 19.3"	- 43.0"
.22LR / (W) / 22LR222HP	36	.084	1,280	937	787	131	70	49	0	- 2.0"	- 6.2"	- 22.3"	- 50.4"
.22LR / (W) / XPERT22	36	.084	1,280	937	787	131	70	49	0	- 2.0"	- 6.2"	- 22.3"	- 50.4"
.22LR / (W) / 22LR333HP	36	.084	1,280	937	787	131	70	49	0	- 2.0"	- 6.2"	- 22.3"	- 50.4"
.22LR / (W) / S22LRUHV	32	.076	1,640	1,033	827	191	76	49	0	- 1.2"	- 4.0"	- 16.1"	- 38.7"
.22LR / (W) / X22LRCBMA	29	.104	770	682	605	38	30	24	0	- 5.3"	- 15.1"	- 48.9"	- 103.9"
.22LR / (W) / X22LRHLF	26	.072	1,650	1,019	812	157	60	38	0	- 1.2"	- 4.1"	- 16.5"	- 39.7"

(Retrieved from mcarbo.com)

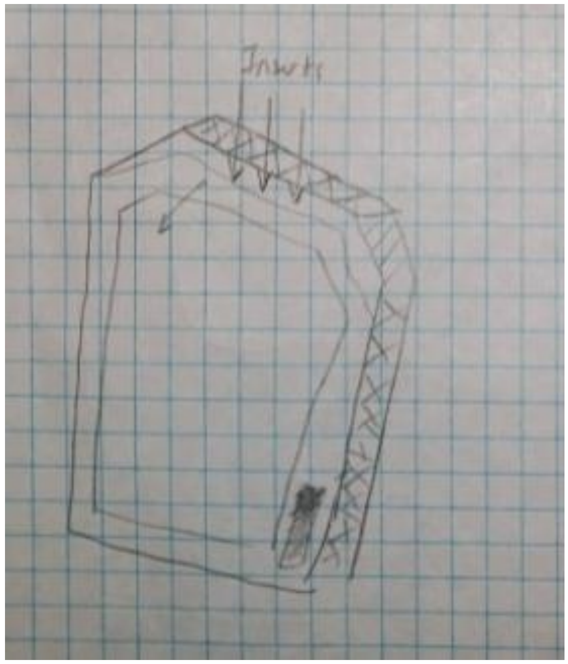
Appendix B Concept Sketches



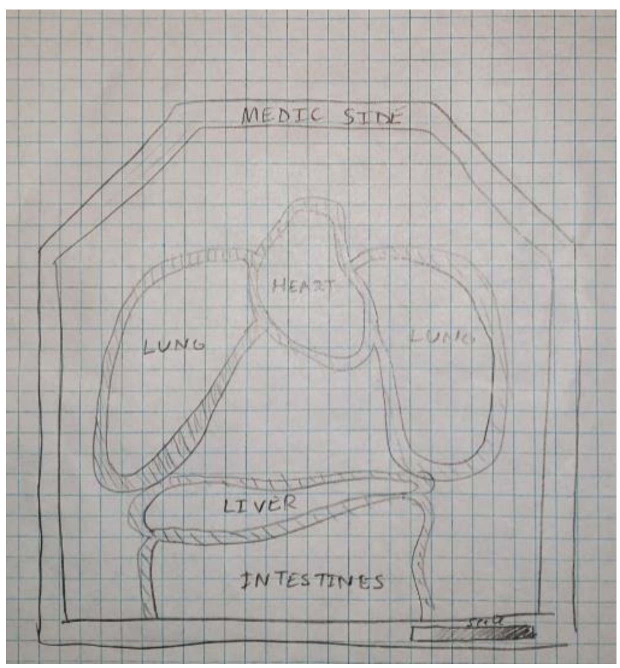
Front View



Film Layer



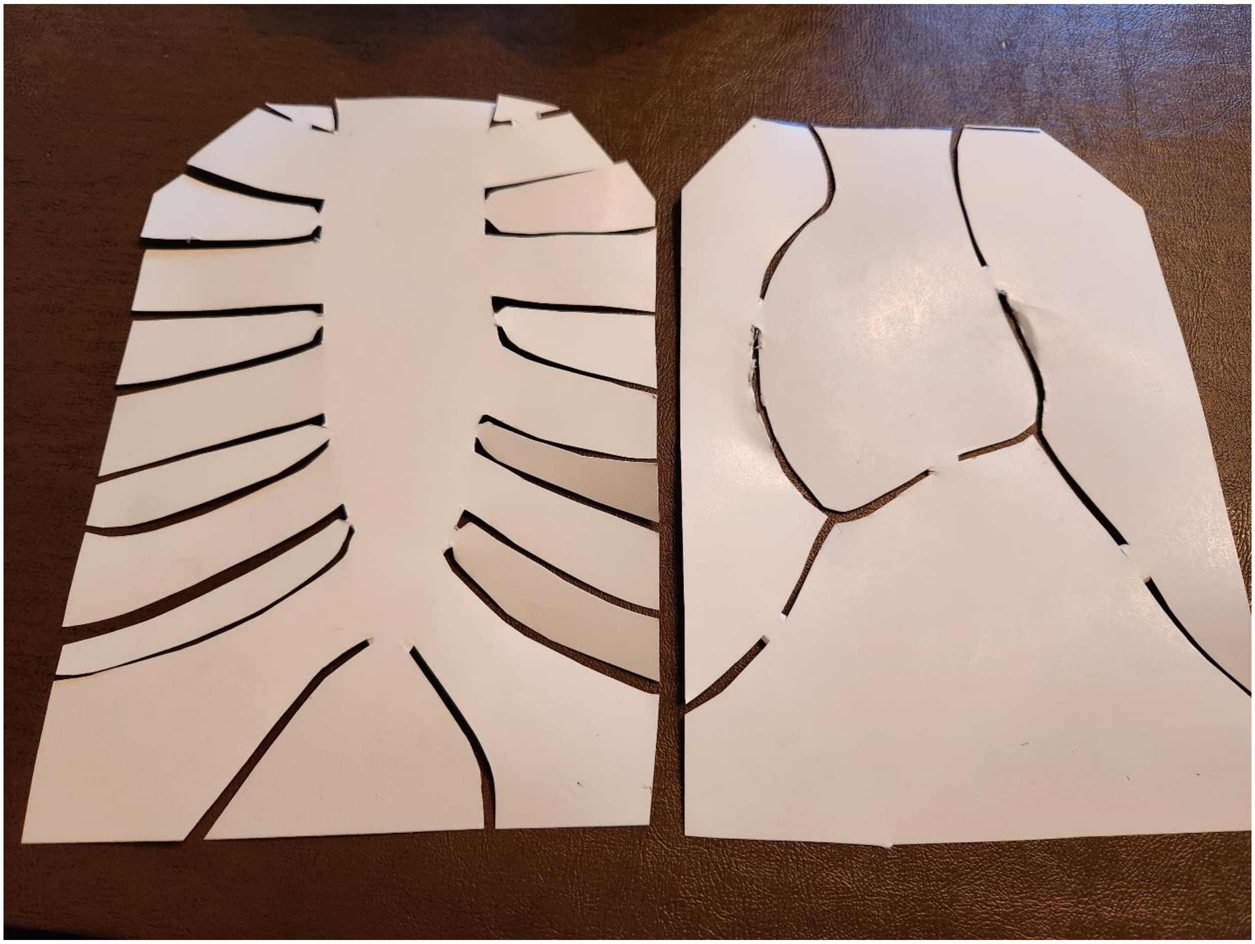
Force Indicator Design As Attached To Trauma Pad



Potential Design For Use As Stencil

Appendix C Embodiment Design

Group Session – Stencil and Prototype Design



Finished Stencils – Skeletal Systems and Major Organs

Using Purchased Materials to Create Prototype

Using Spray Paint to Create Designs to Determine Injured Areas

Finished Product After Spray Painting

Appendix D Testing Pictures

.22LR Ballistic Impact Test – Point of Impact

9mm Ballistic Test – Point of Impact

.357 Magnum Ballistic Test – Point of Impact

Clay Block After .357 Impact