THE DAMAGE BEHIND THE BRUISES:

MITIGATING INTERPERSONAL VIOLENCE THROUGH A DEMONSTRATIVE SIMULATION OF BLUNT TRAUMA ON SOFT TISSUE

A Interactive Qualifying Project

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Abstract

The COVID-19 pandemic increased rates of domestic violence globally, with no proven method to reduce abuser recidivism. Our project aimed to develop a reformative procedure to decrease cases of domestic violence. We designed a durable model thigh, able to endure strong impacts and provide visual feedback on the damaging effect of the blows. We implemented software to gauge impact intensity, and created a qualitative evaluation process to assess the model's effectiveness as an educational tool for mitigating domestic violence recurrence.

Acknowledgements

Authorship Table

Author	Contributions
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1.0   MITIGATING INTERPERSONAL VIOLENCE THROUGH A DEMONSTRATIVE SIMULATION OF BLUNT TRAUMA ON SOFT TISSUE

Interpersonal violence has been on the rise in recent years, with many countries experiencing elevated rates of reported cases. This has been further exacerbated by the COVID-19 pandemic, which spiked the incidence rate by an average of 30% worldwide. Furthermore about 50% of cases of domestic violence go unreported, meaning that the true number of cases is much higher. The goal of this project is to raise awareness about the damage that can be caused by blunt force trauma and prevent the perpetrators of interpersonal violence from becoming repeat offenders. According to the Department of Health and Human Services, over 50% of domestic violence cases result in the victim suffering blunt trauma injuries (Capaldi 2009).

Blunt trauma is an injury resulting from an impact with a dull, firm object. Unlike penetrative trauma which breaks the skin and creates open wounds, blunt trauma usually results in severe bruising, internal bleeding, and in some cases broken bones (Simon et al.). Damage resulting from blunt force trauma is often less visible than penetrative trauma, leading individuals to underestimate injuries. A study by the Griffith Criminology Institute shows that 60% of individuals arrested for domestic violence reoffend within 10 years of their arrest (Broidy et al 2016). Research has found that there were no effective techniques for reducing recidivism rates among perpetrators of domestic violence, with all methods being either ineffective or unproven (Mears 2003). We aim to create a new method to reform the perpetrators of domestic violence, also known as batterers, with the goal of reducing recidivism and overall incidence rate of domestic violence.

To achieve the goal of educating batterers on the impacts of blunt trauma, this project will create a demonstrative tool to educate individuals on the damage done by blunt force trauma. This tool will include a leg model to provide a tangible representation of the effects of violence, allowing users to understand the full extent of the harm caused by blunt force trauma. Additionally, this demonstrative model is designed to be reproducible to extend the social impact of this project to any individual or organization who wants to use it. The leg model is designed to be struck and then externally display the damage caused by blunt trauma that is not always visible to the untrained eye. This procedure will include a survey for participants to gauge their perception of blunt trauma damage. The qualitative procedure of surveying participants serves both to help educate and gain critical data on the effectiveness and impact of the demonstration on participants.

2.0   Pre-existing Work on Blunt Trauma Education

2.1   Blunt-Force Trauma

Globally, people are most exposed to blunt-force trauma through falls, car accidents, and physical assault such as domestic violence, violent riots, fights, etc (Simon et al., 2022). In the case of physical assault, blunt force trauma is the most common form of injury sustained. The assailant uses blunt objects such as household items, bats, and even bare hands (ie. a fist) to beat the assaulted (Savitsky et al., 2021). Trauma injuries are the leading cause of death in adults under 35, with most trauma deaths resulting from blunt trauma (Simon et al., 2022). Despite this, there is a disconnect between the external, visible and the actual injuries sustained through blunt force trauma. This is problematic because it results in a lack of public awareness about the potential severity of these injuries, demonstrating a need for increased education and public awareness.

2.2   Manifestation of Blunt Force Trauma

The manifestation of blunt force trauma is typically less obvious to the untrained eye than other forms of trauma. For example, penetrative trauma typically involves a wound and visible blood. Blunt force trauma typically manifests as swelling, bruising, and internal injury. This lack of visible external injury can cause a disconnect between the severity of the injury and the appearance of the injury.

When blunt trauma occurs, the visible aspects are the formation of bruises, contusions, and wounds. Capillaries and small blood vessels rupture due to the impact of blunt trauma, resulting in the pooling of blood underneath the skin (Simon et al., 2022). This results in a visible bruise. The depth of the injury and the amount of time that has passed since the formation of the bruise are the two factors that most significantly contribute to the color of the bruise. Older bruises are green or purple, while fresh bruises are red or purple (Simon et al., 2022).

Internal bleeding can also occur as a result of blunt trauma. This occurs when the blood vessels within the body are damaged, which causes the blood to go into the tissues surrounding the vessels. Internal bleeding can be very serious, even life-threatening depending on the location. For example, internal bleeding may damage organs.

These internal injuries may not be outwardly visible to an individual not trained to recognize the signs of blunt force trauma. It is important to demonstrate the severity of injury to educate individuals on the impact of interpersonal violence.

2.3   Prevalence of Interpersonal Violence During Social Isolation

Interpersonal violence has been on the rise in recent years, exacerbated by the COVID-19 pandemic. Typically, during a disaster, the most vulnerable members of society get impacted the most. When isolated in groups for long periods of time, tensions rise and there is no outlet. At points, this tension can be expressed through violence and causing physical harm to others, typically those isolated together.
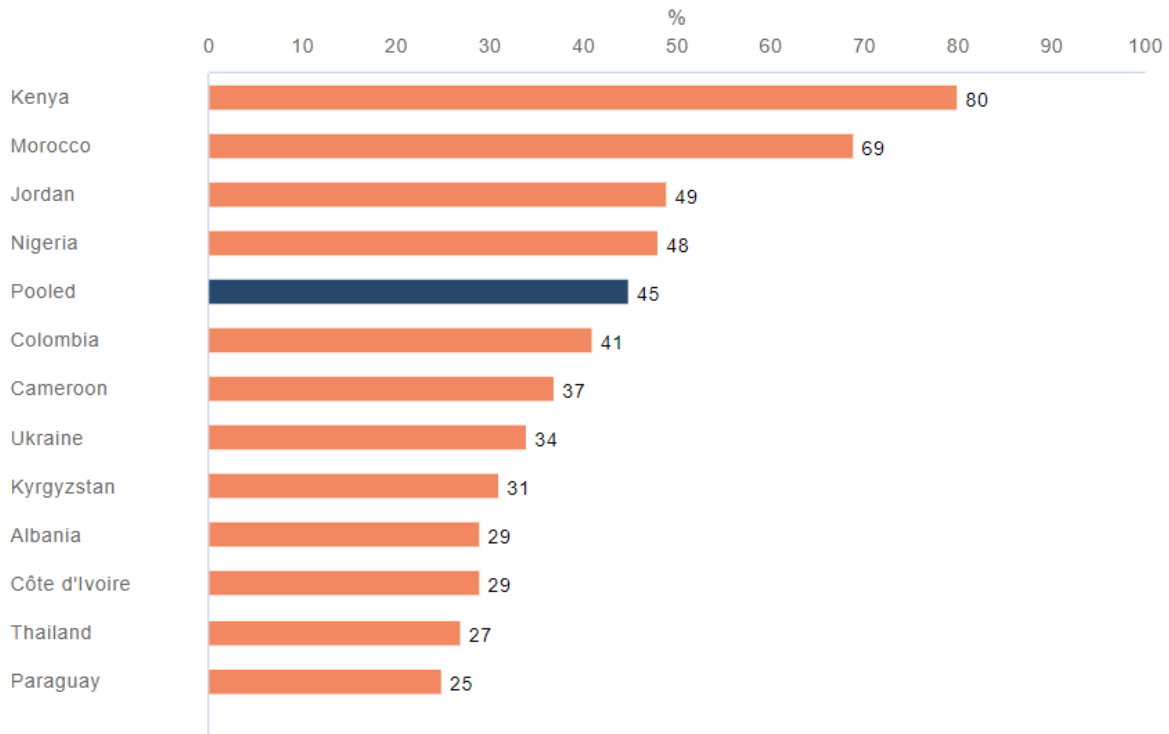
Figure 1: Women who reported that they or a woman they know experienced a form of violence since COVID-19 (%) (UN Women, 2021)

In the United Kingdom it was found that police reports of "interpersonal violence increased by 8.1% during the pandemic period" (Kim & Royle, 2023). However, this problem extends beyond the United Kingdom. A separate study from the University of Athens found the same pattern using publically available domestic violence databases. As stated in the article, the increases in domestic violence cases were "in Chile, 75%; in France, 30%; in India, 32%; in Lebanon, 50%; … and in the United States, 21.5%" (Kourti et al., 2023). Through these findings, it is clear that there is an alarming increase in domestic violence worldwide. A United Nations report found that 50% of women reported that since the COVID-19 pandemic they or a woman that they knew had experienced violence (UN Women, 2021).

2.4   The Real Scope of Domestic Violence

An important consideration when analyzing this data is that many interpersonal violence incidents go unreported. According to the Bureau of Justice Statistics only 56% of 1.3 million nonlethal domestic violence cases were reported between 2006 and 2015 (Reaves 2017). This means that incidences of interpersonal violence during the pandemic are likely significantly underreported, pointing to an even more serious issue. There is a demonstrated need for the prevention of interpersonal violence. This project aims to address this by simulating the impact of blunt force trauma on soft tissue in order to increase public awareness of the realistic impacts of interpersonal violence. This project specifically focuses on mitigating interpersonal violence that results in blunt trauma.

2.5   *Existing Domestic Violence Intervention Programs*

Existing programs for treating the perpetrators of domestic violence have shortcomings in their effectiveness. One of the premiere models for reforming batterers is the Duluth Model, created by Ellen Pence. Part of the Duluth Model is an extensive program aimed at reforming male batterers. Often, this consists of a 27 week non-violence program. However, the effectiveness of this program has not been proven through research. A study by the University of Pittsburgh found that:

> There is no solid empirical evidence for either the effectiveness or relative superiority of any of the current group interventions. Across many rigorously conducted studies, treatment effects are small, if an effect exists at all, when comparing intervention to no intervention (control) (Cluss, 2011, p. 11).

This result has been corroborated by other research. Another study of batterer intervention programs by the National Institute of Justice found that attrition rates within batterer intervention programs are very high, with only 27% of those enrolled completing a 26 week intervention program. Additionally, for those who did complete the program, there was no statistically significant difference in recidivism rates over an extended period of time. A shorter 8 week program, although attendance was much higher, was also ineffective, being indistinguishable from the control group at the 6 month mark (Jackson, 2003, p.19). Extending the length of the program had no impact on efficacy. The state of California made batterers complete 52 week batterer intervention programs, but ultimately concluded that "there is no statistical association at all between programs and an offender's likelihood of re-offense (MacLeod et al)"

Cognitive Behavioral Therapy, or CBT, had also been used as a method for batterer intervention. However, its efficacy is not noticeably different when compared to the Duluth Model. According to a study conducted by Patricia Cluss and Alina Bodea, "Intervention programs widely implemented by states and judicial systems that are based on feminist-psychoeducational and/or cognitive-behavioral approaches
lack empirical backing"
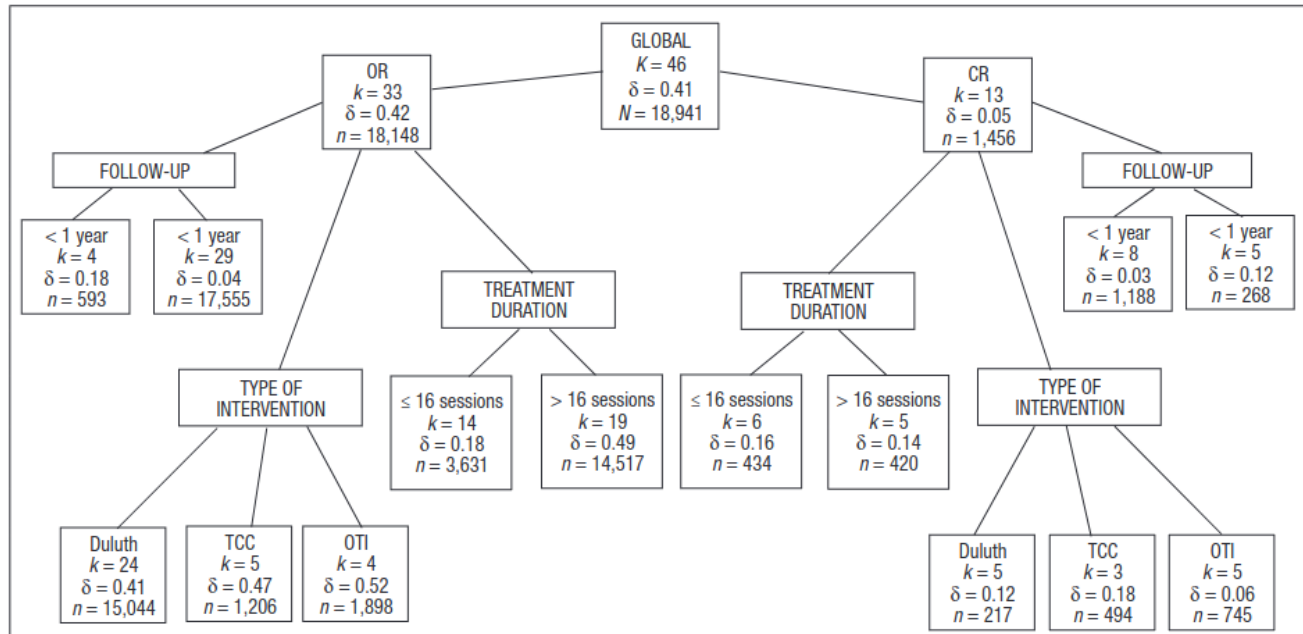
Figure 2: Meta-Analysis of differing Batterer Intervention Programs (Arias et al 2013) Note. OR = Official reports; CR = Couple reports; δ = weighted mean effect size; k = number of effect sizes for each analysis; CBT = cognitive-behavioral treatment programmes;OTI = other types of intervention.

Overall, there is a distinct lack of effective programs for reducing recidivism among batterers. By creating a demonstrative method to show the effects of abuse, we aim to enhance the effectiveness of batterer intervention programs worldwide.

2.6 Existing Simulation Models

Existing soft tissue models have limitations in their demonstrative usage. Demonstrative models need to be able to visually simulate injuries relative to the force of an impact. Research has found no existing models that meet this requirement.

Figure 3: Models used for testing survivability in car crashes (Xu et al., 2018).

Crash Test Dummies (such as those shown in Figure 2) are a commonly used model to understand the impact of blunt force trauma, often used in automobile safety testing (Xu et al., 2018). One significant advantage of these models is that they are typically used to model the whole body, which allows for multiple areas of study in one experiment. However, this limits the specificity that can be provided in one area of the body for focus. Another advantage is that these dummies can vary in weight and size and demonstrate the impacts of a collision on many body types. This is helpful as it allows researchers to demonstrate the impact of the same trauma on different genders, ages, and backgrounds. However, crash test dummies have very low resolution when measuring their results, often only reporting if the crash was fatal or not. They cannot simulate bleeding or bruising, and damages are not specific to any area of the model. There is also no visual feedback for the injuries inflicted, thus reducing the efficacy of the model for spreading awareness about the impact of blunt trauma.
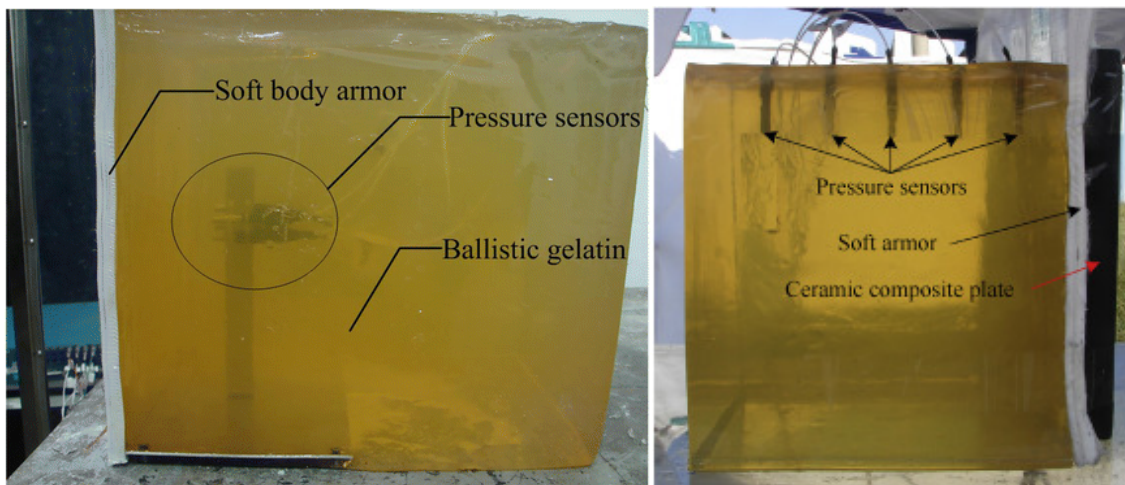
Figure 4: Models used for measuring the effects of Behind Armor Blunt Trauma (Rocksén et al., 2020).

Another existing model is the Behind Armor Blunt Trauma (BABT) ballistics gel target shown in Figure 3. This model is designed to simulate the mechanical properties of human tissue (Han et al.) This is used by firing a projectile at bulletproof plates layered on the gel. The bullet is stopped by the bulletproof plates, however, the energy from the bullet is distributed and transferred to the gel as a blunt impact. Sensors integrated into the gel can measure the force of the pressure wave as it propagates through the material.

While this is useful to simulate the elasticity and viscosity of tissue, it is limited in its ability to demonstrate biological responses. The model is not molded in a human form, thus it is less impactful in bringing awareness to violence prevention. Additionally, there are concerns about the accuracy of the ballistics gel in modeling the response of human tissue, as not all mechanical parameters will be identical. While the ballistics gel can be used to gather data on how an impact might travel through tissue, it does not provide

visual feedback on the damage to tissue caused by impact. It cannot simulate bleeding and bruising.
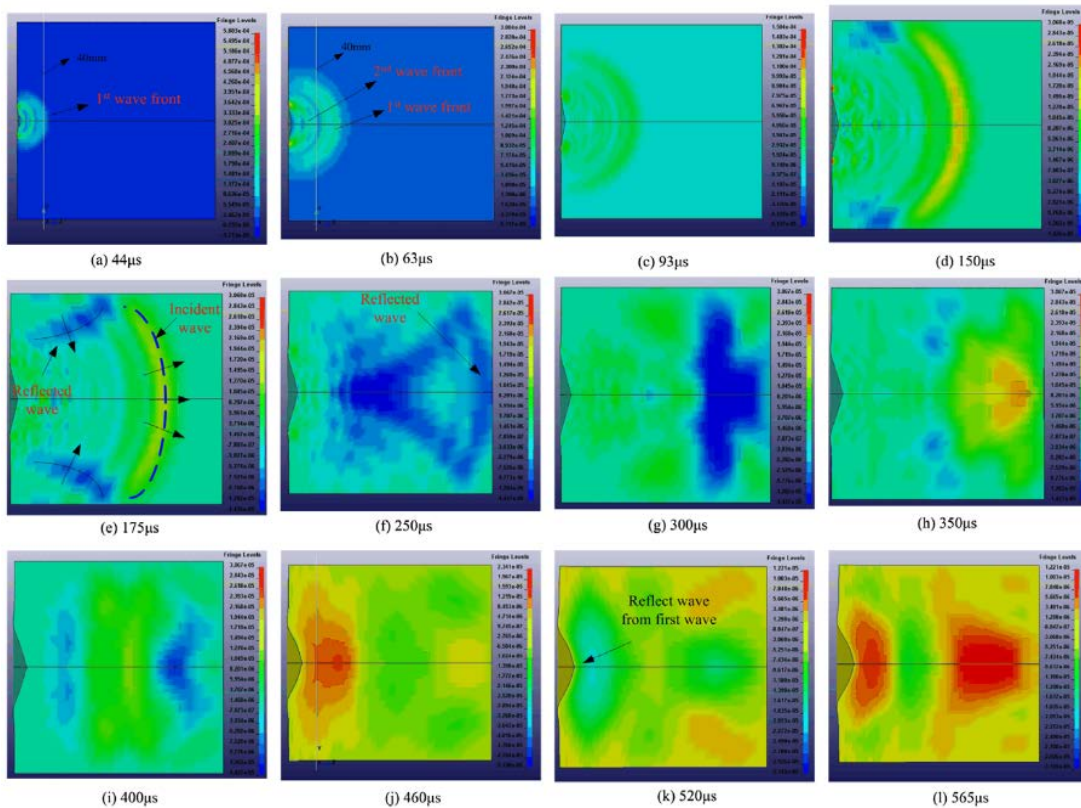
Figure 5: Computer simulation results (Luo Et al 2017).

Computer simulations have also made strides in their ability to study anatomical representations of the body. Computer algorithms can simulate the impact of external forces on the behavior of human soft tissues and bone (Luo et al 2017). These models are more accurate than the previously mentioned models when considering the parameters of mimicking biological responses. They can show bleeding, bruising, and swelling more completely. However, as with all computer models, the accuracy of the model is dependent entirely on the data given to it. Additionally, for demonstrative purposes, a computer simulation is less impactful than a physical model.
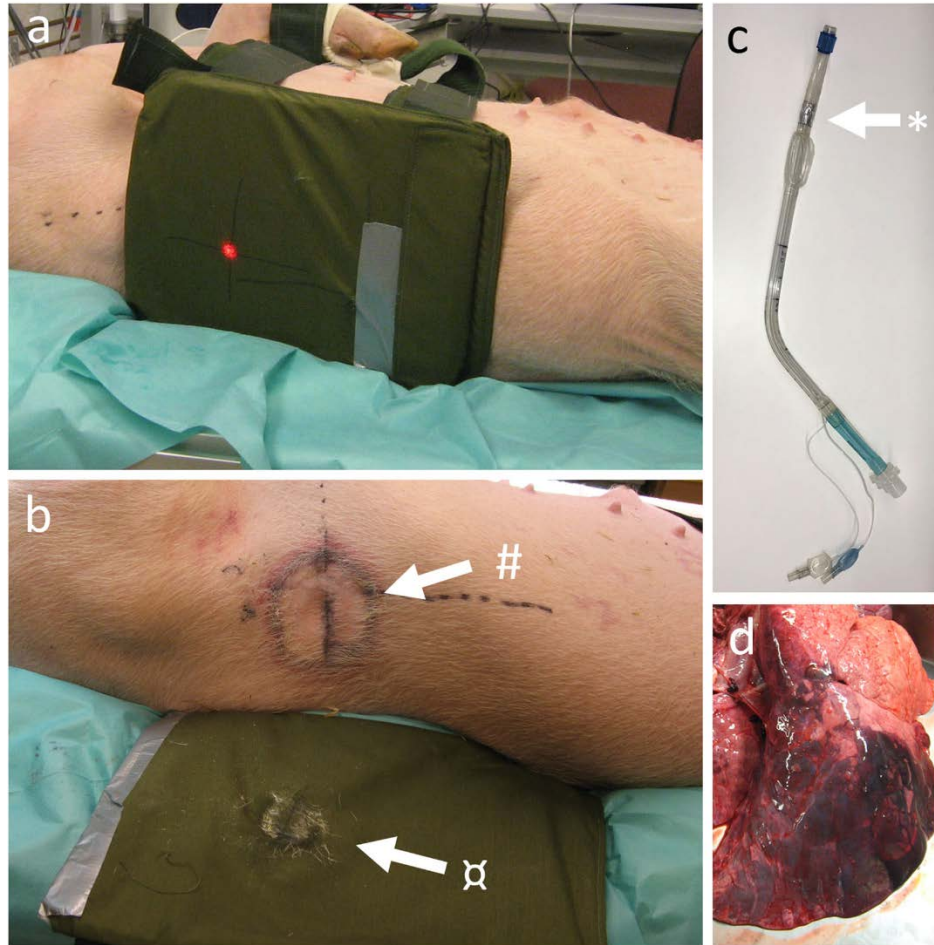
Figure 6: Results from Behind Armor Blunt Trauma testing on pigs, showing experimental setup, images A and B, equipment used to sedate pigs for testing, image C, and internal damage resulting from impact, image D (Rocksén et al., 2020).

Animal and Cadaver testing is sometimes used for reference of injury as shown in Figure 5. Cadavers are extremely accurate as far as anatomy and can be used to study post-mortem impacts of trauma. A limitation of this technique is that it does not allow for studying the biological reactions of an alive individual to trauma injury. Despite their accuracy, there are ethical concerns with the use of cadavers as well as a factor of disgust, detracting from the goals of raising awareness. Transporting and storing the cadaver outside of research facilities is also difficult and expensive, detracting from the versatility of the model. Live pigs are also used to simulate blunt force trauma as they are similar in anatomy to humans (Rocksén et al., 2020). Live porcine tests share the same portability and public disgust concerns that cadaver testing does. Additionally, there are considerable ethical concerns as well as limitations on the accuracy of the physiology. These types of models, although they produce highly accurate results, are not ideal for raising awareness about the impact of violence.

Additionally, it is important to be able to demonstrate the force of the injury, which is a component that other models are missing. When calculating damage caused by an impact, the stress tensor of each layer of tissue should be taken into consideration. Stress tensors are constants dependent on the physical properties of a material, and how it

responds to given amounts of force ("Tensors, Stress, Strain, Elasticity"). These constants can take into account factors such as thickness and strength of the tissue type ("Tensors, Stress, Strain, Elasticity"). The angle and location of impact influence the amount of force needed to rupture tissue. Despite the numerous factors for consideration, a good generalization is that it typically requires less force to damage skin and underlying tissues than bones and organs. An example of this is a force of 10 to 50 pounds is typically enough to bruise the skin, while it may require 100 to 200 pounds of force to break a bone ("Tensors, Stress, Strain, Elasticity").

2.7   *Project Objectives*

The purpose of using this model is to reform batterers to decrease further domestic violence. This method will be more visually realistic and emotionally impactful than other models. As shown previously, current methods for battery intervention have proven ineffective. This project will create a reformational system that integrates interactive demonstration to create a procedure that gives batterers a clear understanding of what blunt trauma is and the extent of the harm they are capable of.

3.0   Methodology of Soft Tissue Simulation

The purpose of this chapter is to illustrate how the project's objectives are accomplished by presenting the research, data collection, and analysis techniques employed. In addition, we will outline the limitations of these methods and provide a Project Timeline (as shown in Appendix A). The project's overall objective is to create a demonstrative model that increases the public's understanding of the impact of blunt-force trauma. To achieve this goal, we started by outlining a set of quantifiable design goals or the model and its components. Based on these goals, we selected a set of materials and designed a model that met the project objectives. We then integrated an electrical and software system that allows for the display of visual feedback. Finally we created a qualitative assessment to assess the efficacy of the model as a demonstrative tool.
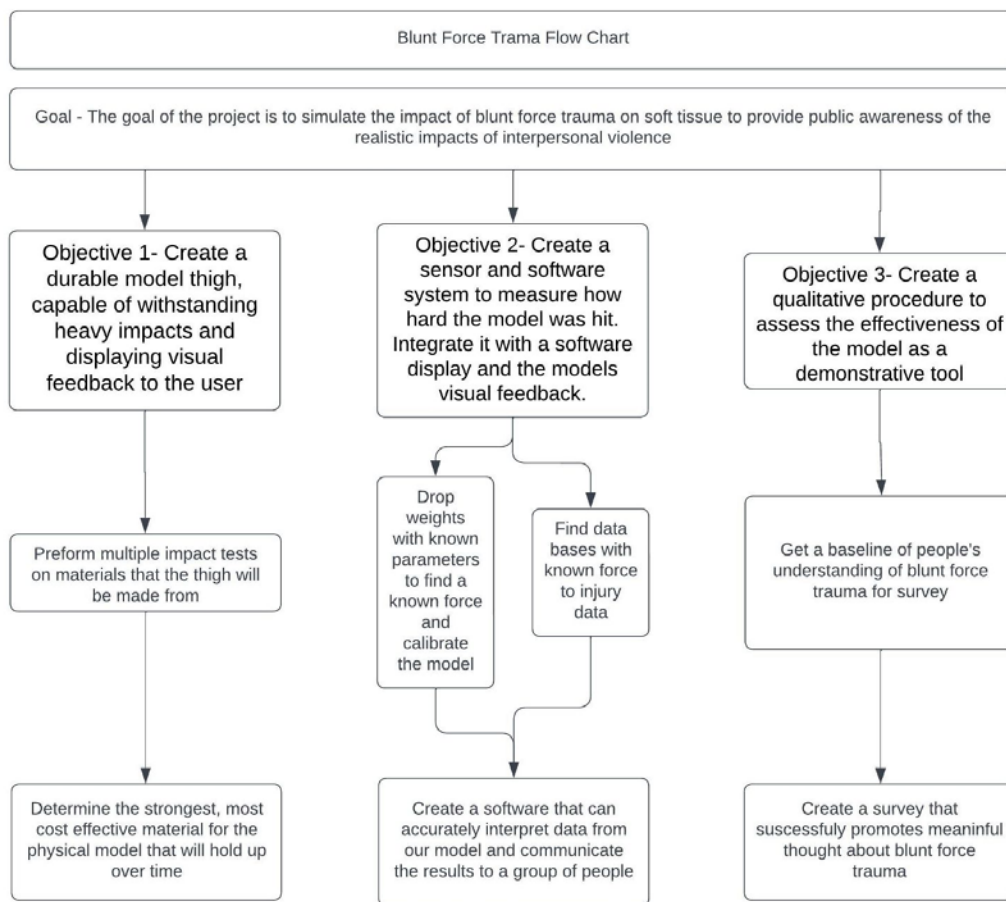
Objective 1: Create a durable model thigh, capable of withstanding heavy impacts and displaying visual feedback to the user.

Objective 2: Create a sensor and software system to measure how hard the model was hit. Integrate it with a software display and the model's visual feedback.

Objective 3: Create a qualitative procedure to assess the effectiveness of the model as a demonstrative tool.

3.1   Model Requirements

The materials used for the model must be durable, and the model should not break after each use. The goal of the project is to be able to simulate someone being struck in the thigh with a club or bat using this model. In this situation, the impacting object contains about 4000 joules of kinetic energy. For a material to be suitable for our model, the material must withstand at least 20 consecutive hits from an object with 4000 joules of energy or more without any visible damage.

Furthermore, it was determined that the model should provide visible feedback on the injuries caused. The model must display feedback representing bruises and internal bleeding in a clear and easy-to-view manner. This feedback is essential to understanding the effects of blunt force trauma and increasing public awareness. The model should be able to be reset easily without the need for special equipment. This makes the model easy to use and maintain, ensuring that it can be used repeatedly for educational and research purposes.

3.2   Model Fabrication

3.2.1   Material Testing

The material selection process included two tests to ensure that they met the project requirements. The purpose of the tests was to identify the most suitable materials for use in the model.

The first test was a material compatibility analysis to evaluate different soft tissue analogs and identify the most similar material to human soft tissue. Materials such as silicone, gelatin, and latex were evaluated to determine their ability to accurately mimic the texture and consistency of human soft tissue. The suitability of the materials was determined through indentation and haptic feedback, where the materials were poked and manipulated to see if they behaved like tissue.

The second test was a durability test to make sure that the materials used in the model are durable and resistant to wear. Test samples were struck with a bat to see how they held up to repeated impact. Additionally, these tests included subjecting the materials to repeated cycles of compression and tension to assess their response. As this model is intended for long-term use, the model must be able to withstand multiple impacts without showing permanent damage which will be addressed in this test. Additionally, the food-based materials were left out for a week to assess their shelf life. With time, gelatin both grew mold and was ripped with use.

The ultimate goal of these tests was to identify the most suitable materials for use in the soft tissue model. The model aims to accurately mimic the visual and physical feel of human soft tissue and withstand the forces associated with blunt force trauma. Ensuring the model is durable and uses demonstrably accurate materials promotes the goal of achieving public awareness of blunt force trauma injuries and withstand years of experimental use. Ultimately, silicone was chosen because it most resembles and behaves like human tissue.

Although we decided on silicone as the material to model soft tissue, it was deemed non-viable to construct the entire leg out of silicone due to cost and mass constraints. We decided to construct a singular "hit window" on the outside of the thigh where the model is designed to be struck. The rest of the model was built around the window and designed to disperse the shock of impacts safely, without damaging the model.

3.2.2   Model Prototyping

The hit window contains silicone to model human skin, along with the sensors and feedback mechanisms to measure and display the force of the impact. In the first iterations of the window, the entire structure was constructed out of 3D printed Polylactic Acid (PLA). However, this material had several problems. Although PLA is rigid, it is also very brittle, and the window was at risk of breaking under high loads. For the next iteration, the borders of the window were printed out of Thermoplastic Polyurethane (TPU), as it is a very flexible material, capable of bending to withstand the harsh impacts the model will sustain. The bottom plate of the window is fabricated out of PLA and contains mounting sockets for the sensor system and LED rings to provide feedback.

As the model thigh is intended to be mounted to a larger manikin, it was necessary to create a "bone" that the window would attach to. For this purpose, a PVC pipe was initially chosen due to its rigidity and strength. In initial iterations, the PVC bone was mounted directly to two end caps made of PLA. These caps would allow the model to be attached to the larger mannequin. However, initial testing found that the structure was too rigid, and risked damaging the caps when the model was struck. Unlike the hit window border, printing the caps out of TPU was not a viable option, as the caps themselves must be rigid to create a solid mounting point. Instead, a custom TPU spring was printed and placed at the joint between the endcaps and PVC bone. This spring allows for some play between the two members, absorbing the shock when the model is struck. We also switched from a PVC to a steel pipe, as it was stronger and had a smaller profile within the model. Although these measures helped mitigate the shock loads, additional dampening was needed between the window and the bone to protect the model.

Initially, the hit window attached directly to the bone. However, the loads placed on the window were too high, and the hit window's PLA backplate would have been at risk of snapping. Instead of mounting the window directly to the bone, it is suspended by several springs within a block of foam. The springs provide shock absorption to the model and dampen harsh impacts. The foam is placed around the bone and fills in the space in the thigh. The foam not only cushions the hit window but also serves to protect the model in case a strike misses the hit window and impacts an unintended location.

3.3   *Sensor Analysis and Model Software*

3.3.1   Sensor Analysis

The model uses an electronic sensor system to measure the force of impact. These sensors both activate the model's visual feedback system and provide data to the software system.

Initially, the model was designed to use a series of four strain gauges placed at the bottom of the hit window absorbing the impact force of each blow. The strain gauges were able to accurately measure the impact force, however, were not able to measure over 50 lbs without the risk of damaging the sensors. Another option was to use wheatstone bridges to measure resistance in circuits and strain gauges which measure resistance based on the strain imposed. These options were not chosen due to the increased complexity of mounting requirements.

The next iteration of the model used a potentiometer to measure the force of the blow. The concept was to use a linear potentiometer alongside a spring to cushion the impact. Given the deflection of the spring provided by the linear potentiometer and the force constant of the spring, it would then be possible to determine the force of impact on the model. Conceptually, the linear potentiometer made sense, however, the implementation provided a few challenges. The largest problem was sizing an appropriate spring that would be capable of providing appropriate deflection for lighter hits while being able to withstand heavier blows. A multitude of springs was tested, including 3D printer bed springs, and high-load rubberized springs. Finding a spring that met these criteria was quite difficult given the parameters of the problem. Additionally, this system of measuring the load required the hit window to be able to move vertically which added complexity to the model.

The third iteration of the model used an accelerometer which measures acceleration instead of a potentiometer. This measured the force through the perceived acceleration instead. The accelerometer measures how fast the model accelerates. Given the mass of the model, the force of impact can be calculated. The advantages of the accelerometer were that it does not need to size a spring, meaning that the model can measure both hard and soft impacts. Additionally, the model does not need to have any moving parts, greatly simplifying the design. However, this sensor proved to be difficult to accurately calibrate, and was not precise enough for use in this project. The accelerometer we had access to also could not measure accelerations higher than 3G's, meaning that the sensor was unable to accurately measure heavy impacts.

The final iteration of the model uses a flexible force sensitive resistor to capably measure large loads up to 445 newtons. The flexible nature of this sensor allows it to survive heavy impacts without sustaining damage and simplifies integration into the model. By placing the sensor between the metal bone and the hit window, it is able to get accurate readings of the force the model is struck with.

3.3.2   Model Software

The physical model relies on a software system to create a fully interactive model. The purpose of the software is to detect the intensity of the impact on the physical model.

The software's objective is to accurately read forces from the sensors, use the lights on the model to provide instant feedback on the impact of the blow to the model, and serve as a visual aid for users during the model demonstration.

A Raspberry Pi Pico was used due to its availability and ease of use. The software was built on the MicroPython framework that came pre-installed on the Raspberry Pi. The software utilized an accelerometer and averaged the measured acceleration for the duration of an impact to reduce excess noise corrupting the data. Using this method, the force of impacts on the model was more easily and accurately measured.

Additionally, the software implemented lights used to simulate bruising from impacts to the leg. To achieve this, two 16-light RGB LED rings were used. These lights were set to a gradient color ranging from red to purple depending on the force of the impact perceived by the accelerometer, to display the severity of bruising.

Alongside the LEDs, an informational dashboard was also designed to further explain the impact. The initial design for this system used a web server hosted on the Raspberry Pi that could be accessed by demonstration participants via the WiFi network. It was decided that this was an overcomplication of the design and that a simple Serial/USB connection with a separate application would be much more effective given the timeframe. Additionally, the webserver posed other problems such as WIFI access and other connectivity issues. Instead, a two-component software system was used that read data from the Serial/USB connection of the Raspberry Pi and converted this to a visual display.

3.4   Qualitative Assessment and Procedure

To assess the effectiveness of the model, a qualitative procedure was created. Although this project involves creating the procedure, administering it is not within the scope of this project.

The qualitative procedure will consist of a set of surveys designed to assess the disconnect between the public's perception of the impacts and the actual damage that occurs. Before interacting with the model, participants will complete a pre-survey to evaluate their baseline knowledge of blunt trauma. This will also determine the participant's perception of how blunt force trauma manifests. After completing this pre-survey, participants will then strike the model. The model's feedback will be delayed so the participant cannot see the simulation. The participant will then record their estimate of the damage to the model including bruising, internal bleeding, and broken bones. After completing the first survey, they will then be shown the model feedback from their strike. Finally, they will complete a post-survey, where they answer reversed versions of the questions in the pre-feedback survey. These questions will ask what kind of injuries people would sustain in certain accidents, to determine if they have been made more aware of the impacts of blunt trauma. These questions were reviewed by Dr. Keren Mazuz, an anthropologist, to ensure the efficacy of the questions. These survey questions are shown in Appendix C.

3.5   Ethics and the Institutional Review Board

This research project concerns the creation of a physical model thigh along with its accompanying software components. While direct interaction with human subjects will not be needed for this project, the procedures established could be used in future studies that involve human subjects. Therefore, a review by an Institutional Review Board (IRB) was necessary to ensure the well-being of all participants in future research.

The research team recognizes the importance of obtaining IRB approval before conducting any research. After consultation with WPI's IRB it was determined that this project was exempt from extended IRB review due to its low level of interaction with human subjects.

4.0   Results and Discussion

To successfully complete this project, three main objectives were met.

Objective 1: We created a durable model thigh, capable of withstanding heavy impacts and displaying visual feedback to the user.

Objective 2: We created a sensor and software system to measure how hard the model was hit, integrated with a software display and the model's visual feedback.

Objective 3: We created a qualitative procedure that can be used to assess the effectiveness of the model as a demonstrative tool.

The result of these objectives was a procedure and custom model to be used in demonstration. The model was able to produce simulated bruising according to the force it was hit with, and showed this bruising via LED lights with varying intensity and color. The model effectively simulated bruising similar to the bruising that would occur on human tissue when struck with a comparable force. Additionally the feedback from the model includes not only the bruising but also puts the strength of the impact in context using qualitative comparisons via a display screen.

Additionally, the model met a series of requirements for this project in order to be a viable solution for reducing interpersonal violence. Firstly, the model had to have similar enough mechanical properties of human tissue, so that when it was struck it behaved like skin. This was achieved by using a foam that would not deform too much or bounce back too quickly when struck. Durability of the model was a very important consideration. Materials were tested by striking them repeatedly to see what would break. The model we created was able to withstand the forces it was struck with without breaking or cracking. This model successfully demonstrated visible feedback when struck to simulate the injuries that would be caused to a human.
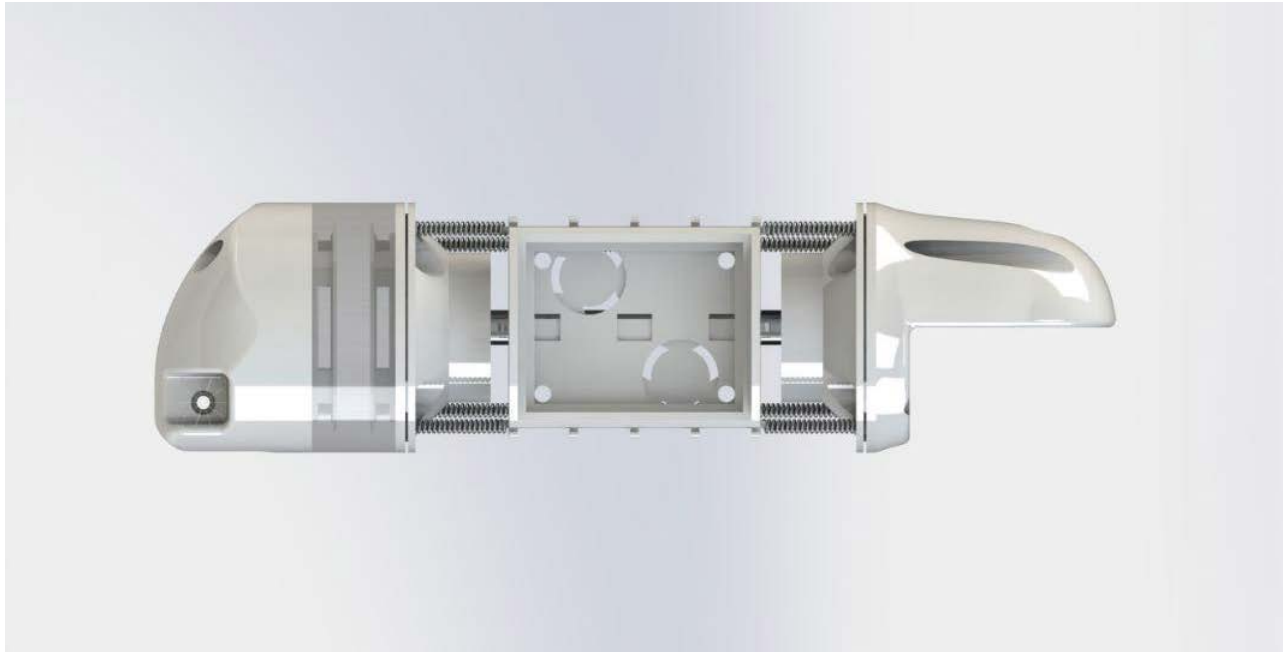
Figure 7: Solidworks render of 3-D components of leg model

4.1   Model Specifications

4.1.1   Model durability

The material used to model soft tissue for this project was silicone. It went within the hit window constructed on the outside region of the thigh. The silicone is the portion of the model made to be struck.
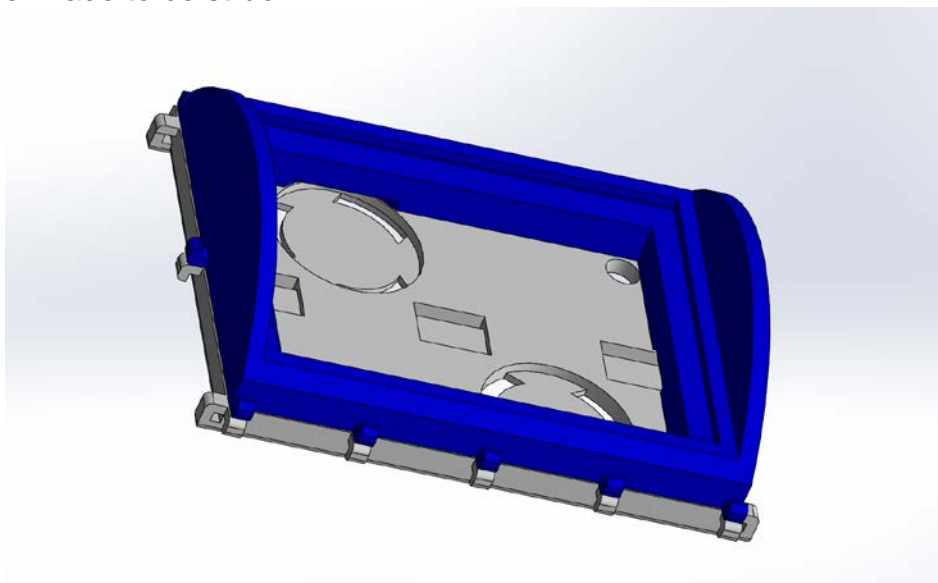
Figure 8: Solidworks drawing of hit window that will contain silicone

The silicone successfully did not crack or rupture when struck, making it an ideal material choice. Additionally, silicone has similar enough mechanical properties of human tissue, so that when it was hit it behaved like skin. The hit window also contains sensors to measure the force of the impact. The borders of the window were printed out of Thermoplastic Polyurethane (TPU), as it is a very flexible material. When hit, the TPU does not crack or break successfully meeting the durability requirement.
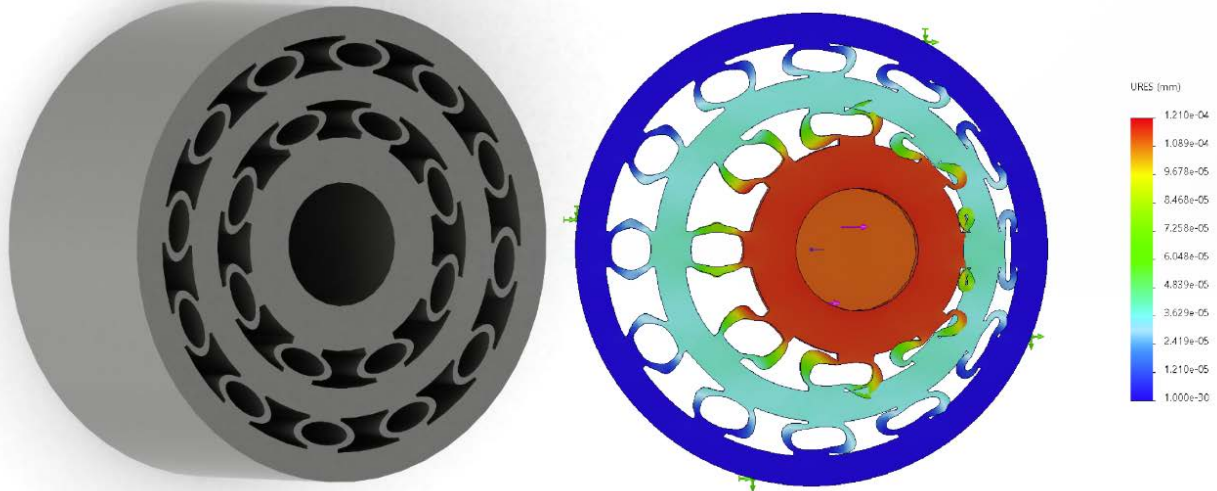
Figure 9: Solidworks rendering of TPU spring for shock absorption and Solidworks analysis of force dispersion
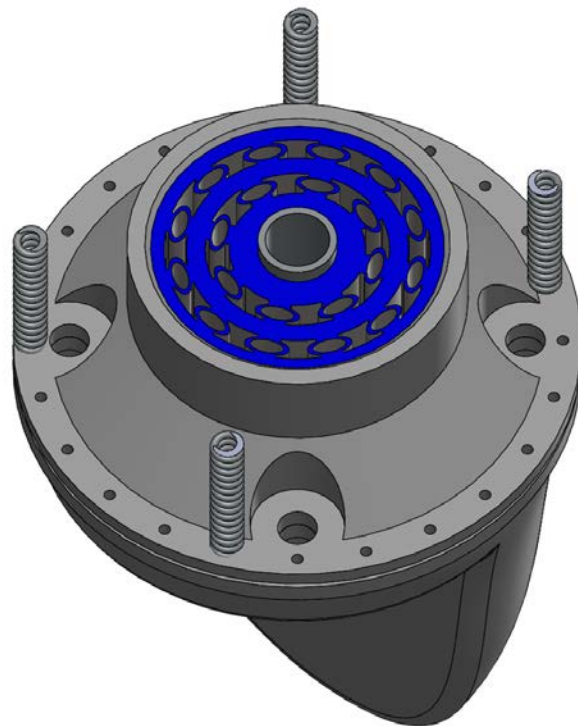
Figure 10: Solidworks drawing of TPU spring (blue) placement within leg model

There is a 3-D printed TPU spring between the steel pipe which represents the bone and the endcaps. This spring effectively absorbs the shock when the model is struck. Additional damping is provided by foam between the window and the bone to protect the model. The hit window is suspended by several metal springs within a block of foam. The springs provide shock absorption to the model and dampen harsh impacts. The foam is placed around the bone and fills in the space in the thigh, cushioning the hit window and providing protection against strikes that miss the hit window.

4.1.2   Sensor Analysis

The demonstrative model was capable of utilizing its force sensitive resistor to detect the force the model was struck with.
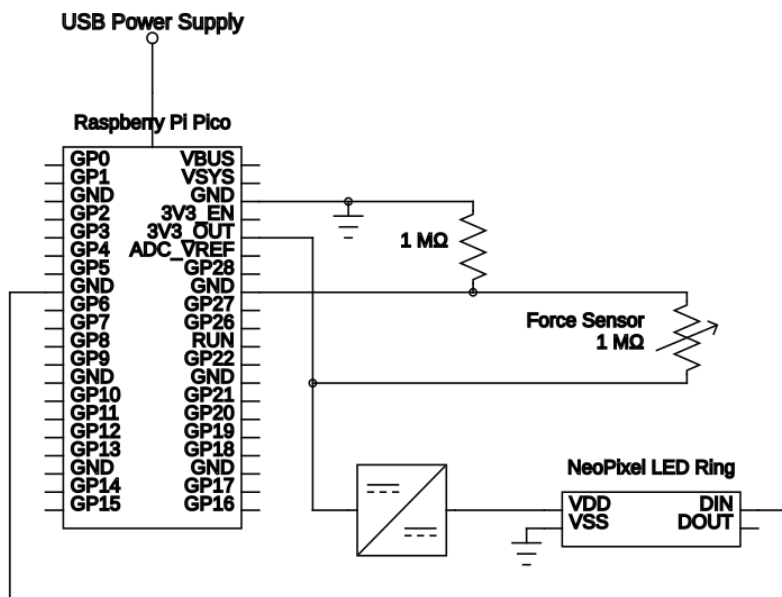
Figure 11: Electronic schematic showing use of force sensitive resistor
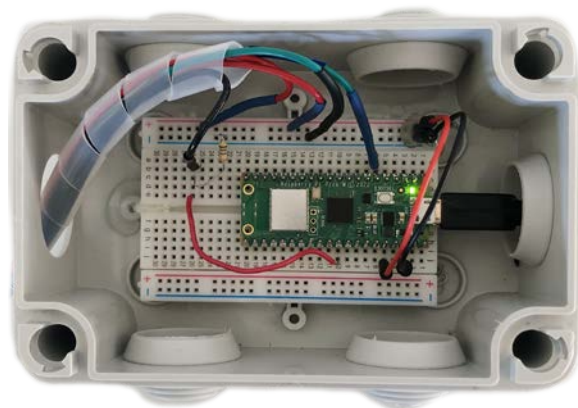
Figure 12: Electronics Box

The flexiforce sensor changes resistance with force. To make the resistance change effect a change in voltage, it is implemented into a voltage divider, with a 1 Megaohm resistor in series with the sensor.

Measured Resistance over Force
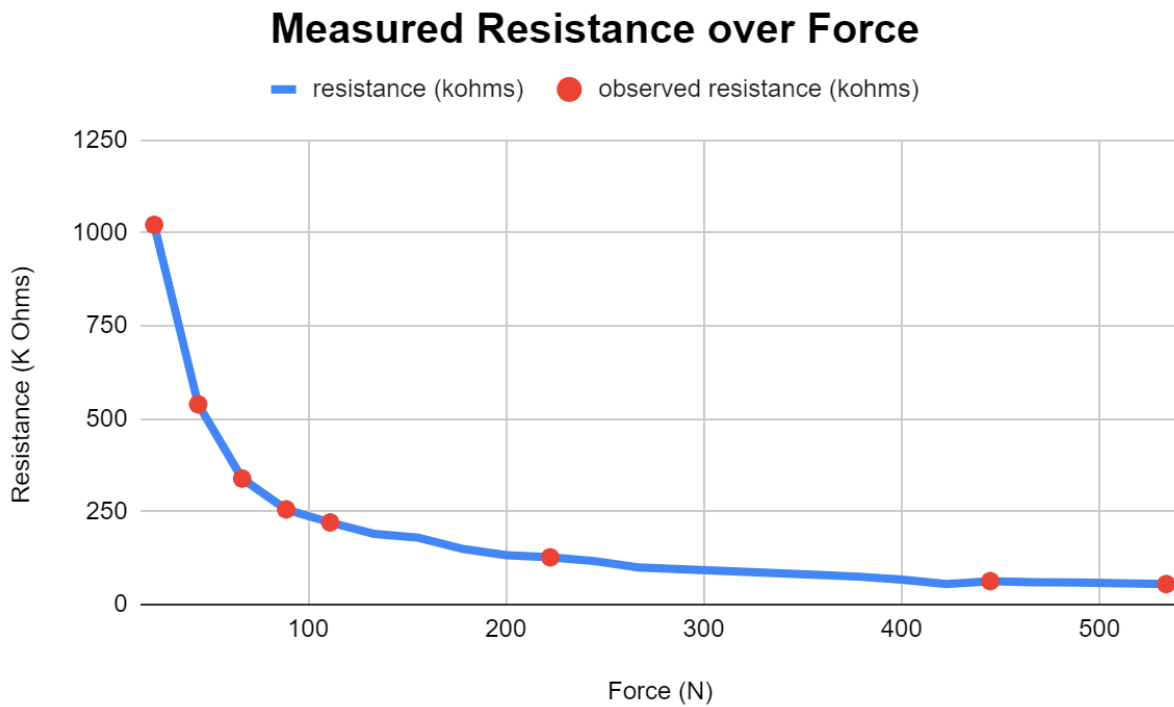
Figure 13: Sensor calibration data (blue) compared to tested values for comparison

As the model absorbs an impact, the resistance of the force sensitive resistor varies with the hit strength. Then, the resultant voltage was converted to an approximate force. The greater the voltage is, the higher the force is. This conversion was compared to the sensor data sheet.
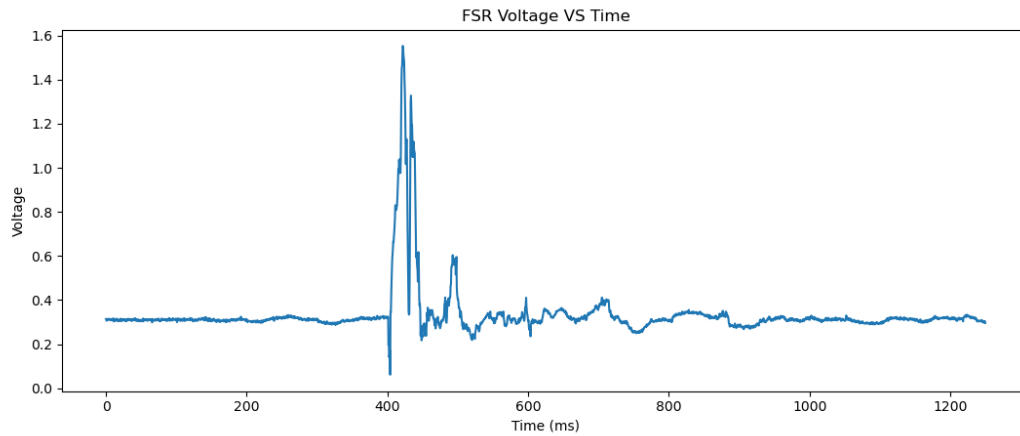
Figure 14: Raw sensor data of a force being applied to the model
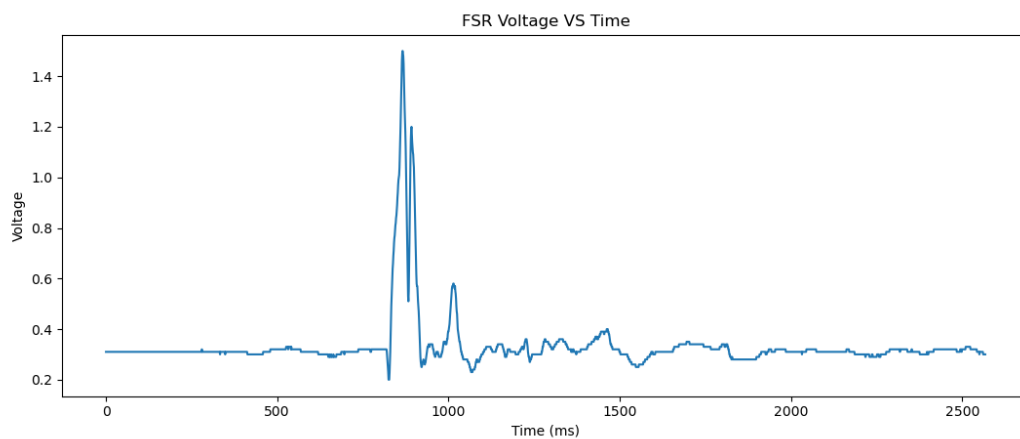
Figure 15: Filtered sensor data of a force being applied to the model

The raw data from the sensor is then smoothed by applying an averaging filter to remove noise. This causes there to be one main peak on the large force spike, instead of a jagged line. That way then the algorithm to find the peaks of the spike can detect the main peak of the spike instead of all the peaks along the jagged spike. The peak force was then detected.

4.1.3   Model Software

The physical model successfully creates an interactive model through the software system which accurately detects the force of impact, and provides feedback using a 16-light RGB LED ring on the model.

Figure 16: Model with hit window removed to expose ring light that is controlled by software

The lights operated on a gradient, depending on the force the model is struck with. With a more intense strike the lights are set to a purple color representing more intense bruising, with a lighter strike the lights are set to a red color, representing light discoloration.
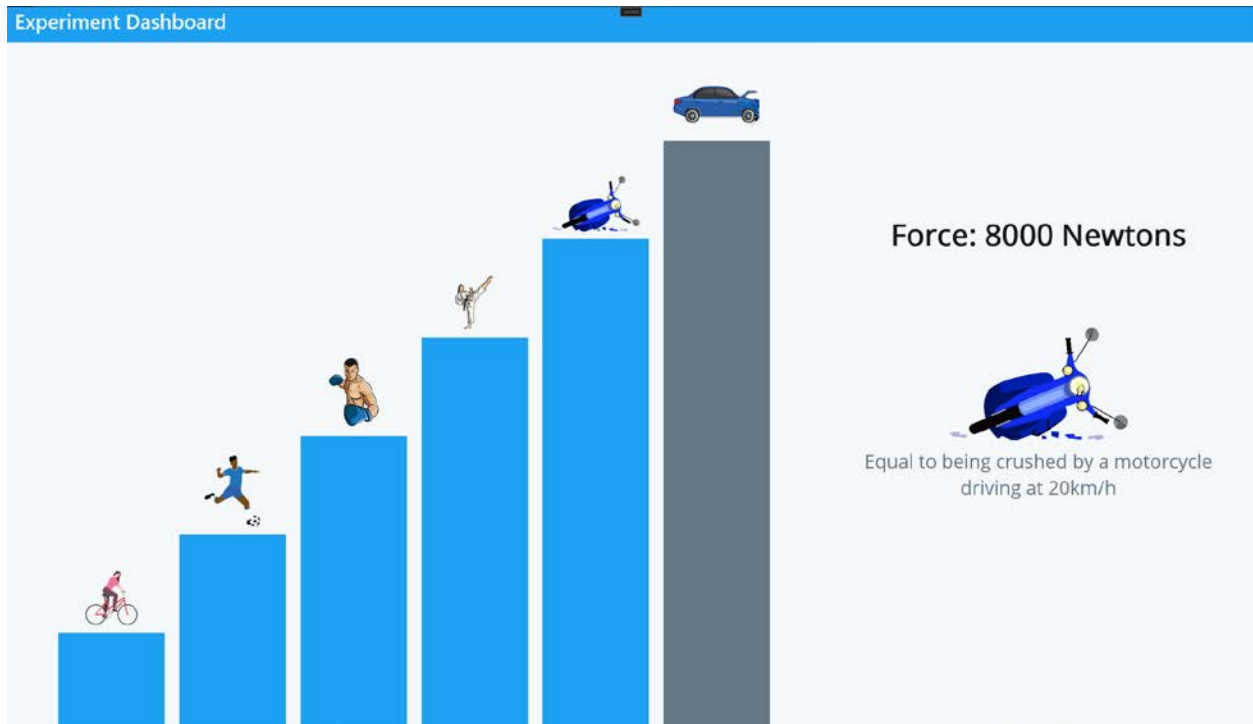
Figure 17: Software interface

The software has a user interface that takes the force the model was struck with and provides context. For example, If hit with a force of 8000 newtons, the software will put that into the context that that is equivalent to the force of a motorcycle crushing an individual driving at 20 km/hr.

4.2   Qualitative Assessment and Procedure

This procedure to measure the efficacy of the model was successfully created, however administering this procedure and monitoring the impact of the procedure is outside the scope of this project due to time constraints. The procedure is designed to reduce the disconnect between the perpetrator's perception of damage and actual damage.

Procedure:

1. Administer pre-survey
2. Allow participants to strike model
    a. Delay model feedback
3. Administer survey to determine the batterers perception of damage done
4. Show model feedback from strike
5. Administer post-survey

The surveys are in Appendix B.

4.3   Discussion

The tool that we have created as a result of this project is a new method of batterer intervention. Current methods of reducing interpersonal violence have proven ineffective over time, typically only showing results short-term. To increase the effectiveness of this project compared to current methods, it has a physical demonstrative component to enhance the reformative impact. It is the goal of this project to reduce future incidences of interpersonal violence by educating the batterers on the true effects of their violence. This project aims to do this by showing the batterers the full impact of their actions as blunt force trauma does not typically display the full extent of the damage externally. This way, the batterers are confronted with the reality of their actions and must face the damage caused.

The designs for this model are also available to the public, so that this project is reproducible and can be used by other individuals and organizations to extend the impact of this project. The procedure, model's CAD files, code files, and instruction files were made public to make the project accessible for anyone worldwide to download, build, and use. By making these designs accessible, we hope to broaden the social impact to reach more communities.

Although we successfully created a useful tool for a demonstrative batterer intervention program, there are limitations to its capability. The physical model is only capable of simulating bruising. A more advanced model could be upgraded with the ability to simulate swelling, along with providing feedback on all surfaces of the model increasing the overall accuracy and realisticness of the experience. By creating a larger hit window, it would allow batterers to interact more freely with the model. This model could also be expanded to other limbs to create a more comprehensive experience for the user. Additionally, future iterations of this project would ideally increase the accuracy of the impact measurement sensor. However, aspects of this model could be used for future models such as the impact sensor design. The model's mechanical design can measure and withstand large impact forces repeatedly.

Although we created a tool for a demonstrative batterer reform program, a comprehensive study to assess its effectiveness was outside the scope of this project. While a procedure was created to test the effectiveness and impact on users, the administration of the survey created for this purpose is out of this project's scope. This procedure may need to be modified when data on its effectiveness is collected. Studying the effectiveness of a batterer intervention program is a highly resource intensive procedure that would not be possible in the timeframe of our project. This is because properly assessing the effectiveness typically takes 10 years, in order to fully assess recidivism rates. Typically, batterers will not recidivate shortly after completing a program, and sustained monitoring is needed to properly assess the impact (Cluss). Performing a sustained multi-year study that would be needed to properly assess the impact is not feasible for our project given the timeframe and resources available.

5.0   Conclusion

This project created a demonstrative tool to be used as part of a batterer intervention program. This tool is aimed at mitigating the recent increase of instances of interpersonal violence, and addressing the shortcomings of current batterer intervention programs. The model we created was able to display bruising when hit in order to bridge the gap between the perceived and actual damage caused by blunt force trauma. Additionally, software was created that explains the equivalence of the force, putting it in context by comparing it to an instance such as being hit by a professional boxer, or the impact of a car crash. A procedure was also created for use with the model, so that perpetrators of interpersonal violence could get the maximum impact out of this tool. It is the goal of this procedure that battereres will realize the extent of damage they are causing after hitting the model, causing them to reconsider hitting a human being. The design of this project will be made available to anyone who wants to recreate it, in the goals of extending the impact of this work.

This demonstrative tool was designed to reduce cases of domestic violence. During the Covid-19 pandemic, individuals were isolated together for long periods of time, resulting in a rise in tensions with no outlets. At points this tension can be expressed through violence and causing physical harm to others. The goal of this project was to make abusers realize the damage they do beneath the skin and understand the magnitude of force they are using. We want to cause a change in behavior as people confront the reality of their own strength and make them think twice before they hit someone again.

6.0   Project outcomes

6.1   Recommendations for Future Models

The model we produced was capable of detecting the force it was struck with and providing visual feedback. However, there are areas of focus that could be improved upon for future model iterations.

Currency, the mannequin the model is mounted to is very lightweight and not representative of an average person's body mass. This means that when struck, the mannequin moves more than it should. A heavier and more durable mannequin would be more robust and provide a more accurate platform to measure the forces behind bows.

Another step would be expanding model coverage to encompass more of the human body, along with improving the feedback mechanisms to be able to model more types of injuries. This would include improving the bleeding feedback to be more realistic, along with integrating more sensors into the hit detection system to more accurately measure the force of impacts.

For next steps, we recommend expanding the feedback mechanisms of the leg to include a swelling response along with improving the visuals of the bruising response. We also recommend implementing sensor fusion between an accelerometer and the force sensitive resistor to better measure the force of an impact.

6.2   Recommendations for Future Procedures

Although we created a procedure for use with the model, we were not able to administer it. We recommend that future projects make using and assessing our tool in a demonstrative context a high priority.

Although properly assessing the effectiveness of the tool for batterer intervention would take years, hosting a workshop for the public would also be a good assessment of the model's efficacy. We recommend hosting an interactive public workshop and surveying participants about the impact the model made on them, and how much the results differ from their perception of blunt trauma.

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8.0   Appendices

Appendix A: Project Timeline

In order to best prepare for the project, model materials will be identified before transitioning to Israel. Additionally, preliminary designs will also be created before heading to Israel to ensure optimal use of time upon arrival. Once there, work will begin to start fabrication of the model which will likely take three weeks. Following this, the last week will be spent doing data collection with the model on how participants would go about using it for demonstrative purposes.

	FEB				MAR				APR				MAY				
Enter the date of the first Monday of each month -->		3	0	7		3	0	7		0	7	4			5	2	9
Gather Materials	■	■	■															
Collect/test materials		■	■	■														
Design model			■	■	■	□	□	□										
Budget final design				■		□	□	□										
Build										■	■	■						
Revise Design						□	□	□	□									
Test and gather data															■			
Survey model effectiveness															■			
Report and conclude												■	■	■				

Appendix B: Project Software, CAD Files, and GitHub

GitHub Repository:

https://github.com/Amitai5/BFT-Simulation

The repository includes the following files:

Firmware Folder: This folder contains all of the firmware files for the Raspberry Pi Pico Wireless. The two files in the folder are used to reset all the data on the Pi and/or flush the firmware.

Code Folder: This folder contains all of the code files for the project, including the main program and any libraries or packages that were used. The code was written in Python and runs on a Raspberry Pi Pico Wireless.

CAD Folder: This folder contains all of the CAD files for the project, including the 3D models of the components, the assembly instructions, and any other relevant design files. The CAD files were created using SolidWorks and can be viewed and edited using SolidWorks or any other compatible CAD software.

Appendix C: Survey/Questionnaire

Informed Consent

Dear Participant,

We are conducting a research study on Blunt Force Trauma Simulation and would like to invite you to participate. The purpose of this study is to provide participants with an educational experience on the impact of blunt force trauma on the human body. Your participation is entirely voluntary, and we would like to ensure that you have all the information you need to make an informed decision about whether or not to participate.

Please read the following information carefully and ask any questions you may have before deciding whether or not to participate.

Purpose:

The purpose of this project is to raise awareness of the impacts that blunt-force trauma can have on the human body, more specifically soft tissue.

Procedures:

If you decide to participate, you will be shown a demonstration of blunt force trauma using a model and a blunt object. This demonstration will be conducted by a trained professional and will be done in a controlled environment to ensure the safety of all participants.

Risks and Benefits:

The demonstration may cause some participants to experience discomfort. However, the potential benefits of this study include gaining a better understanding of the impact of blunt force trauma on the human body.

Record Keeping and Confidentiality:

All information collected during the study will be kept confidential. Only the research team will have access to the data collected during the study and all data collected will be held on a secure platform/server.

Voluntary Participation:

Your participation in this study is entirely voluntary. You may choose to withdraw from the study at any time without penalty or consequence. If at any time you do not wish to answer a question, or a question makes you uncomfortable you may leave that question

blank. If you wish to end the study, you may also do so at any point during the experiment.

Compensation or Treatment in the Event of Misconduct or Injury:

While the demonstration is not expected to cause any harm, it may cause some participants to experience emotional distress and/or discomfort. In any case, you as a participant do not give up any of your legal rights by signing this statement.

Contact Information:

If you would like to inquire further about this project, please contact the procedure administrator at _____. Additionally, if you wish to speak with the Institutional Review Board that approved this project, please contact Ruth McKeogh at irb@wpi.edu or call her at (508) 831 - 6699.

By signing below, you acknowledge that you have read and understood the information provided above and that you voluntarily agree to participate in this study.

Please Write Out Your Full Legal Name.

_____

Please Sign Below.

_____

Demographics Questions

1. What gender do you most closely identify with?

    ○ Male

    ○ Female

    ○ Non-Binary

    ○ Other: _____

2. What is your age?

    Your answer

Pre-Simulation Questions

Before the simulation of the damage has started, please fill out the following questions. The following questions are intended to gauge your perception of damage inflicted by blunt trauma. Please answer each of the following questions with a rating of 1 (least) to 7 (most).

1. On a scale of 1-7, how much would it hurt if you were hit with a baseball bat on the thigh?

	1	2	3	4	5	6	7	
Least	○	○	○	○	○	○	○	Most

2. How many days after being hit with a baseball bat on the thigh would it take for you to be able to go back to work (walking without a limp)?

_____ days

3. On a scale of 1-7, how likely would a person need to go to the hospital after being hit with a baseball bat on the thigh?

	1	2	3	4	5	6	7	
Least	○	○	○	○	○	○	○	Most

4. On a scale of 1-7, how likely are you to break your bone from being hit in the thigh with a baseball bat?

	1	2	3	4	5	6	7	
Least	O	O	O	O	O	O	O	Most

5. On a scale of 1-7, how much would it hurt to be kicked on the thigh?

	1	2	3	4	5	6	7	
Least	O	O	O	O	O	O	O	Most

6. How many days after being kicked on the thigh would it take for you to be able to walk without a limp?

_____ days

7. Would you be more likely to break a bone from being hit with a baseball bat or a wooden spoon?

O Wooden Spoon

O Baseball Bat

O They are equally likely to break a bone

8. Would you be more likely to go to the hospital from being hit with a baseball bat or a wooden spoon?

       ○ Wooden Spoon

       ○ Baseball Bat

       ○ They are equally likely to break a bone

9. When being hit with something like a baseball bat or a metal spoon, what causes bruising?

_____

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Post-Simulation Questions

Please do not answer the following questions until after the Blunt-Force Trauma Simulation is done. If you are unsure when to move on, ask the instructor and he/she/they will let you know.

The following questions are intended to gauge your perception of the damage inflicted after having seen the simulation of the damage. Please answer each of the following questions with a rating of 1 (least) to 7 (most).

1. On a scale of 1-7, how much would it hurt if you were hit with a baseball bat on the thigh?

	1	2	3	4	5	6	7	
Least	O	O	O	O	O	O	O	Most

2. How many days after being hit with a baseball bat on the thigh would it take for you to be able to go back to work (walking without a limp)?

_____ days

3. On a scale of 1-7, how likely would a person need to go to the hospital after being hit with a baseball bat on the thigh?

	1	2	3	4	5	6	7	
Least	O	O	O	O	O	O	O	Most

4. On a scale of 1-7, how likely are you to break your bone from being hit in the thigh with a baseball bat?

	1	2	3	4	5	6	7	
Least	O	O	O	O	O	O	O	Most

5. On a scale of 1-7, how much would it hurt to be kicked on the thigh?

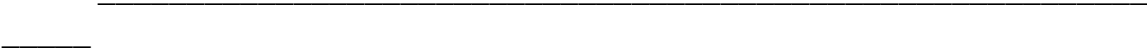|	1	2	3	4	5	6	7	
Least	O	O	O	O	O	O	O	Most

6. How many days after being kicked on the thigh would it take for you to be able to walk without a limp?

_____ days

7. Would you be more likely to break a bone from being hit with a baseball bat or a wooden spoon?

O Wooden Spoon

O Baseball Bat

O They are equally likely to break a bone

8. Would you be more likely to go to the hospital from being hit with a baseball bat or a wooden spoon?

- ◯ Wooden Spoon
- ◯ Baseball Bat
- ◯ They are equally likely to break a bone

9. When being hit with something like a baseball bat or a metal spoon, what causes bruising?

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