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Research Methods Article

Method to Investigate Contusion Mechanics in Living Humans

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Abstract The method utilizes equipment designed to determine variables, which influence bruising mechanics in living human subjects. The device allows weights to be dropped in a controlled manner onto an impactor lying on the skin surface to measure and analyze bruise mechanics. Measured impact characteristics included peak force, peak pressure, impact displacement, tissue stiffness, impact velocity, pressure impulse, force impulse, kinetic energy and the energy transmitted through the limb. Using kinetic energy, transmitted energy and area in contact with the skin we estimated energy absorbed by the limb and energy density (J/m^2). Only energy absorbed by the limb varied significantly according to logistic regression in the subject that was tested and could therefore be used to determine contusion tolerance in that specific case. Hence, the method may be used to determine mechanical parameters required by a striking implement to induce contusions in a particular individual during crime scene reconstructions.

Keywords forensic science; contusion; bruise; biomechanics

Purpose A new relatively easy-to-use method to investigate contusion mechanics in living humans has been developed. The method is described in detail so a non-engineer could use the technique to determine the minimum impact energy required by a striking implement to induce contusions of a particular individual during crime scene reconstructions. While we show that the experimental design and methods can be used to investigate various impact factors that affect contusion formation in a single subject, larger sample sizes are required to assess the techniques ability to be generalized if such a goal exists. However, due to the plethora of anatomical, medical and physiological variables that affect contusion formation we think it highly improbable that this technique should or could be used to compare data across the masses. Rather, we envision the method to be used as an investigative tool for individual incident reconstructions and to experimentally determine the effects of a single mechanical, anatomical, medical or physiological variable on the development of contusions.

1 Introduction

Limb bruises or contusions acquired during non-criminal situations are of relatively low importance as they heal quickly and may even go unnoticed during the event, such as those acquired during sporting events. However, contusions being used as an evidence in a criminal matter can contribute to the conviction or exoneration of a suspect. Hence, the area deserves a thorough investigation. Although many qualitative case and clinical studies involving post mortem contusions have been published, few of them present quantitative data or describe definitive data useful for forensics purposes in the living [8,11]. Typically, these studies cover three main areas of interest: (a) age of contusion; (b) wound/bruise patterns; (c) mimicking or artifacts [4,5,8,9,10,11]. Few publications could be found relating actual impact characteristics to contusions [2, 3]. Further, the impact variables examined and recovery mechanisms investigated in these two studies were tailored to muscle contraction, sport performance and the development of sports equipment, not forensics. If the impact variable magnitude of the incident could be derived from contusions and definitively matched to other physical evidence or statements, we could gain insight into otherwise convoluted cases. Although an area of mechanics research called “impact biomechanics” focuses a great deal of attention on human tolerance testing, no articles could be found in this area or the area of contusion threshold or the impact characteristics that cause such injuries [6,7]. Thus, in forensic science there exists a need for deriving impact characteristics necessary to cause contusions and to develop a method to assist in making decisions regarding suspect alibis and victim statements.

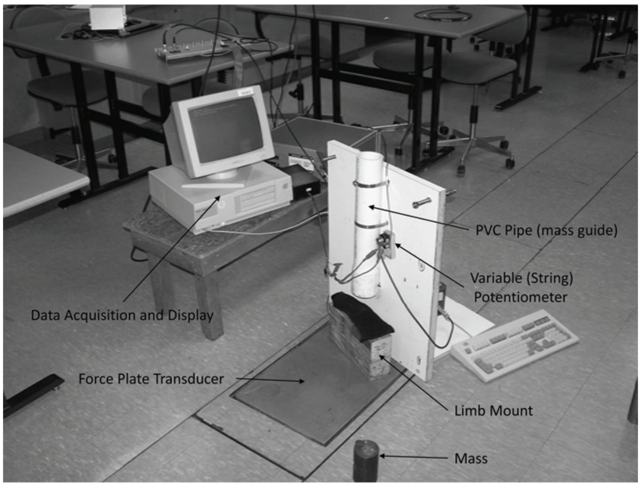


Figure 1: Entire impact system. (Impact apparatus on floor in white.)

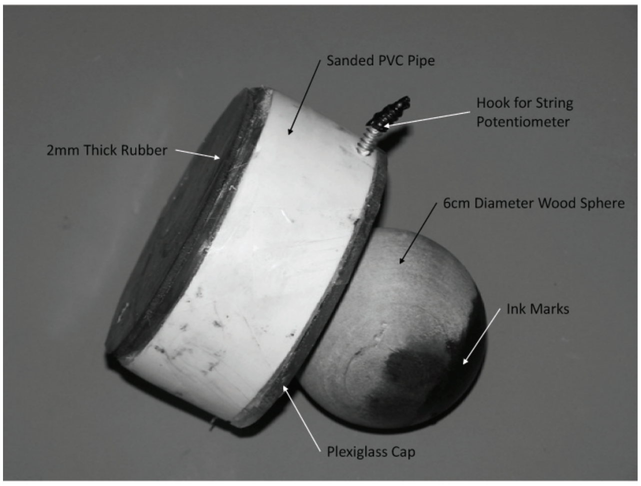


Figure 2: Impactor with attached wood sphere (diameter = 6 cm), potentiometer attachment and two millimeter thick piece of rubber.

2 Materials and methods

2.1 Ethics and subjects

Ethics approval for this study was obtained from Simon Fraser University's Human Research Ethics Board. It was understood that we would need to cause mild injury (contusions), however, based on the anatomical regions being tested, the protocol was deemed as "minimal risk". This study was performed on a single living human (GD). The single subject was a 34-year-old caucasian male who was in good medical condition and had no history of contusions over the test areas prior to the experiment.

2.2 Impact recording system

The equipment consisted of an impact apparatus (plywood and PVC pipe), an impactor, a limb mount, force plate transducer with amplifier (Kistler 9281B), a variable potentiometer (Mico-Epsilon WPS-500-MK30-P) and two different masses (1.9 and 2.6 kg) (see Figure 1). Force and potentiometer data were recorded at 2000 Hz using a 486 computer with a DASH-16 data acquisition card made by Metrabyte.

2.3 Recording transmitted impact energy

Resting the limb on the limb mount under the PVC pipe, one of the masses was dropped from a known height down the opening of the PVC pipe to land on the impactor resting on the surface of the skin. The force plate transducer was located under the limb rest (Figure 1). The impactor (Figure 2) and limb mount are sufficiently stiffer than that of the limb such that their compliance is negligible to that of the limb. Further, the limb responds not only like a spring but also like a damper during the time of impact. Since damping properties absorb energy and are velocity dependent, energy absorption occurs during typical "impact" conditions. Therefore, the tissues damping properties will absorb energy by the time peak displacement is reached. Hence, the energy calculated by the integral of the force by displacement curve as measured by this system will be less than the initial kinetic energy of the projectile just prior to impact. The difference between the two is the magnitude of energy absorbed by the tissue.

2.4 Impactor

The impactor, the device actually impacting the skin, was designed using a PVC joint (larger diameter) for fit and a 6 cm diameter wood sphere for a contact point to reduce high-pressure areas on the skin (Figure 2). The relatively large diameter was chosen to increase the contact area differences between different tissues. For example, over a bony surface such as the dorsal surface of the carpals (wrist) a very small portion of the impactor would actually touch the skin, however, over softer tissues such as the posterior leg (calves), the impactor would spread much of its surface area over the impacted area. This increased the range of contact areas available to analyze. The wood sphere was marked with ink just prior to impact so that the area coming in contact with the skin could be measured. The mark left by the ink was measured for diameter in two dimensions and recorded for each trial. A variable potentiometer was attached to the impactor. Since the impact of a two mass system is complex, the impactor was designed to be as light as possible. Therefore, the impactor was hollow but capped at its ends and a steel tube placed in the center transferred the impact to the wood sphere efficiently. Weighing 150 g, the impact of the falling weight would not be impeded

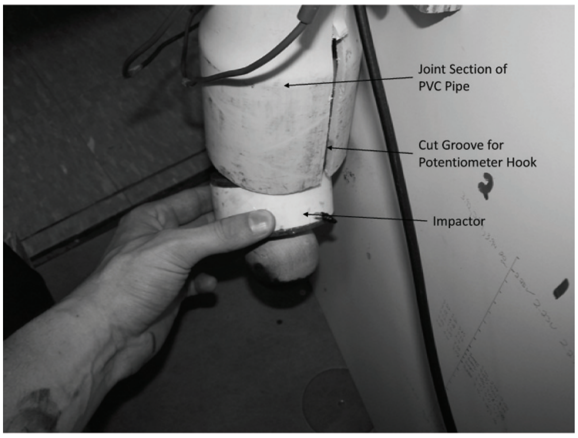


Figure 3: Impactor being placed in the enlarged diameter section of the PVC tube of the impact apparatus.

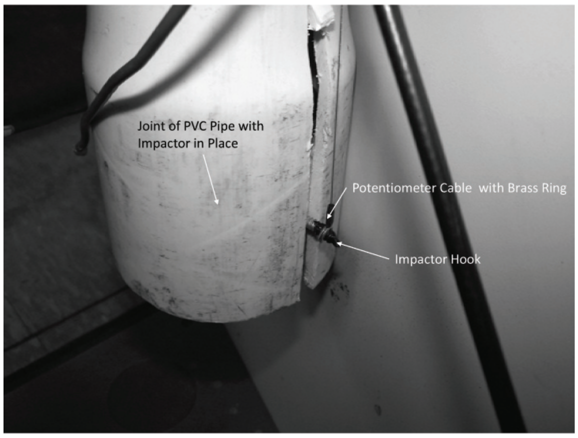


Figure 5: Spring loaded variable potentiometer attached parallel to impactor motion (plane of dropped mass).

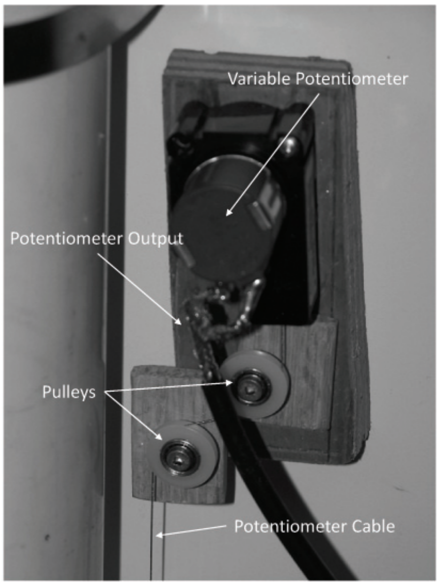


Figure 4: 0–5 V spring loaded variable potentiometer affixed to impact apparatus.

significantly. A two-millimeter thick piece of rubber glued to the top of the impactor attenuated most high frequency vibrations caused by the dropped mass (Figure 2).

The impactor was used at a joint section in the main PVC pipe that is designed to fit tightly. Thus, 2–3 mm of clearance was obtained by sanding the impactor's outer surface to reduce its overall outer diameter, decrease friction and allow for ease of sliding (Figure 3).

2.5 String potentiometer

The variable potentiometer (Micro-Epsilon WPS-500-MK30-P) affixed to the apparatus utilized pulleys that oriented the cable of the potentiometer parallel to the motion of the impactor (plane of dropped mass) (Figure 4). This ensured that friction between the cable and potentiometer was minimized and that the voltage change due to the change in cable length was linearly related to the actual distance traveled by the impactor. A calibration test in the form of measuring the change in voltage for a given change in cable length determined that the potentiometer output varied by 0.09 V/cm.

Figure 5 depicts the manner in which the cable of the potentiometer was attached to the impactor. The tip of the cable was tied around a small brass ring that was attached to the impactor hook prior to dropping the mass.

2.6 Limb mount

The subject was instructed to relax their limb on the limb mount prior to dropping the mass (Figure 6). The base of the limb mount was made of wood and the area in which the limb actually rested was a neoprene covered metal form shaped to match limb geometry. The neoprene added comfort and reduced high frequency artifacts. Reproducibility of limb placement was determined by aligning bony structures with the flat section of the limb mount. The forearm was aligned so that both the radius and ulna bones run parallel with the ground. The leg was oriented so that the flat anterior section of the tibia was parallel to the ground. These placements are only important if we are to use the method to investigate a particular aspect of contusion mechanics. If using the current method to recreate an injury (injury reconstruction), it would be best to attempt to match the orientation of the limb being impacted to that of the actual injured limb if known. For example, if a bruise on the arm that was actually involved in the incident was located over the outside elbow area (lateral epicondyle of the humerus), then the arm should be oriented in the device so that the impactor rests on the same location during the impact.

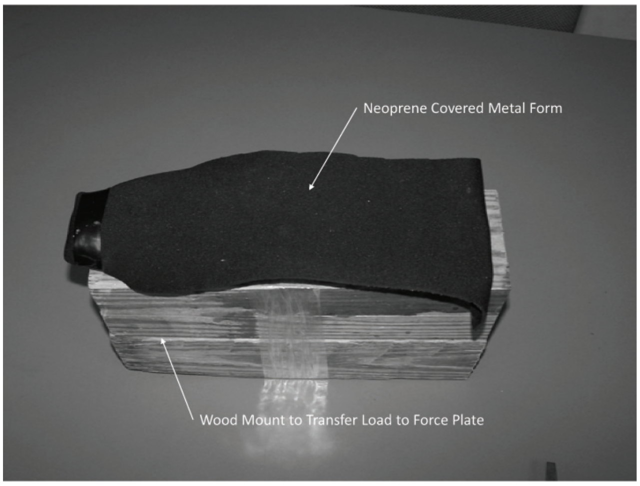


Figure 6: Limb mount.

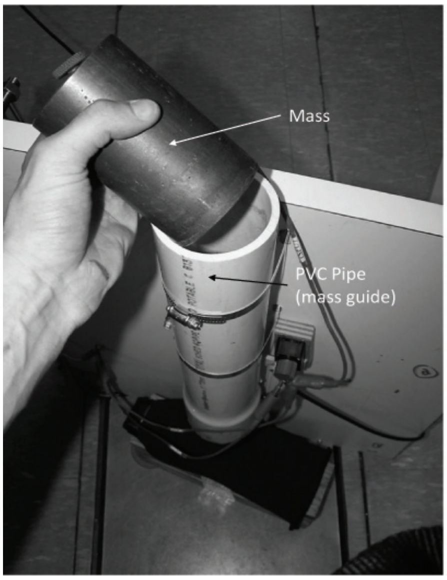


Figure 7: Example of how weights were dropped within the PVC tube.

2.7 Mass-tube interaction

Two different masses (1.9 kg and 2.6 kg) capable of producing different impact energies were used. The diameters of the masses versus the PVC pipe diameter chosen ensured free fall of the mass after release. Hence, the tube acted only as a guide and did not introduce significant friction into the free fall of the dropped mass. Various diameters of masses can be used as long as (a) contact with the PVC pipe does not significantly reduce velocity. This can be verified with a chronometer (speed trap) with falls from the same height with and without the pipe; and (b) the mass does not twist significantly to flip within the PVC pipe as this could potentially cause a double impact. The mass of the weight was marked and aligned with the top of the opening of the PVC tube to maintain consistent drop height (Figure 7). This mark can be anywhere on the mass as long as the overall drop height is known and kept consistent.

2.8 Preparation of impact apparatus, impactor, limb mount and limb

For each impact, the limb was placed on the limb mount on the force platform directly underneath the PVC pipe of the impact apparatus. We ensured that the full area of the bottom of the limb mount remained on the force platform so that the impact apparatus did not interact with it during recording. If the forearm was being impacted, the radius and ulna were placed parallel to the ground by supinating the forearm/hand (palm up) and fixing the elbow at 90 degrees. This orientation allowed both the radius and ulna to absorb the impact equally. As well it centered the muscle bodies of the wrist flexors under the impactor. If the lower limb was impacted, the calf was positioned either tibia (shin) up or tibia (shin) down. If the position was shin up, the impactor rested at right angles to the medial surface of the tibia and if the shin was placed down then the impactor was placed in the middle of the triceps surae muscle body. The wood sphere was then marked with ink. The impactor was placed inside the PVC tube and the brass ring of the variable potentiometer was attached. The tip of the wood sphere of the impactor was then lightly placed on the skin of the limb about to be impacted.

2.9 Data collected

A total of twelve impacts were performed, six impacts were performed using the 1.9 kg weight on one leg (3 shin, 3 calf) and six impacts using the 2.6 kg weight on the other leg (3 shin, 3 calf). The impacts were evenly spaced along the length of the limb. Twenty four hours after impact, the impact area was examined for contusions. If a contusion was present, its location, size, color, and shape were noted. The diameter of the impact area was measured in two dimensions, as delineated by ink marking. From the recorded force, displacement, and impact area, many impact characteristics could be calculated.

2.10 Data analysis

Peak pressure was calculated by dividing the peak impact force by the area of the circle left by the pen ink. The equation used to estimate the area of the circle left by the ink was

$$\text{Area} = (\pi * d^2)/4,$$

where "d" equals the average between the two diameter measurements taken from the mark left by the ink.

Tissue stiffness was estimated by dividing the peak force by the maximum displacement as measured by the force platform and the variable potentiometer.

Impact velocity is defined as the average rate at which the skin was depressed by the impactor, and was estimated by dividing the maximum displacement by the time difference from impact initiation. Impact velocity should not be confused with velocity at impact, which is the velocity of the dropped mass just prior to impact. Assuming complete free fall of the mass, velocity (v) of the mass at impact equals

$$v = \sqrt{2gh},$$

where "g" equals the acceleration due to gravity (9.81 m/s^2) and "h" equals the relative height above the impact point to which the mass was dropped.

Force impulse was estimated by calculating the integral of the force-time curve (see Figure 8). The integral or area under the curve can be numerically estimated by using the Trapezoidal Rule of Newton-Cotes closed integration formulas. The method is clearly explained on pages 586–590 of the fifth edition of "Numerical Methods for Engineers" edited by Steven C. Chapra and Raymond P. Canale [1]. However, the basis of the method can be summed up in the following recursive equation:

$$I = (b - a)*\left[\left(f_{(a)} + f_{(b)}\right)/2\right],$$

where "I" equals the integral, "a" and "b" equal the step size between two data points and "$f_{(a)}$" and "$f_{(b)}$" equal the magnitude of the function at data points a and b, respectively. Hence, the area under the curve can be calculated by the sum of I's for each pair of data points. The faster the data acquisition the more accurate the method, the time between data points in this experiment was 0.5 ms.

Pressure impulse was calculated by dividing the estimated force impulse (F*s) by the area (m^2) of the mark left by the ink previously described to achieve the unit Pa*s and then further divided by 1000 to get the unit kPa*s.

The impact energy transmitted through the limb was estimated by calculating the area of the force-displacement curve. Thus, what is calculated is the area of the hysteresis (upstroke of data does not match downstroke of data) loop of the force-displacement curve.

The theoretical impact energy was estimated by calculating the kinetic energy of the dropped mass at impact. The kinetic energy (KE) of a dropped mass (m) equals

$$\mathrm{KE} = 0.5\,\mathrm{m}^*\mathrm{v}^2,$$

where "v" equals the theoretical velocity at impact as discussed above.

The energy absorbed by the limb was estimated by calculating the difference between the theoretical energy at impact (discussed above) and the impact energy transmitted through the limb (discussed above).

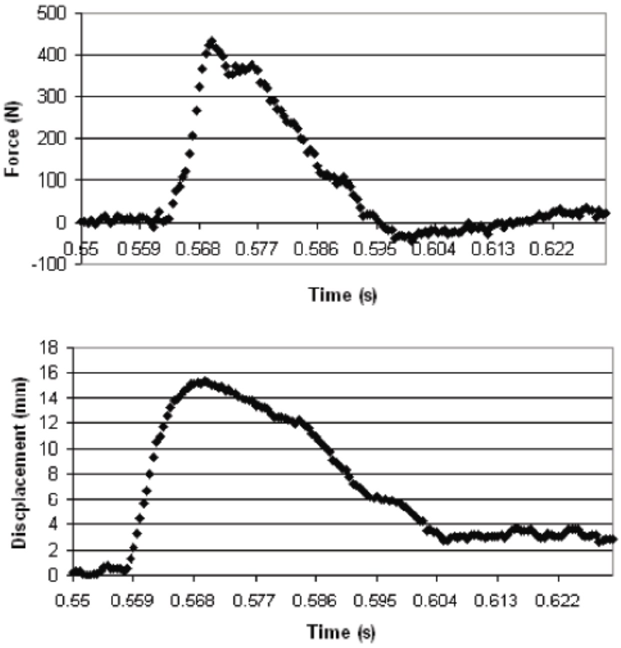


Figure 8: Typical impact force (top) and displacement traces (bottom).

The energy density was estimated by multiplying the theoretical impact energy (8 J for trial #1–6 and 11.5 J for trial #7–12) by the area of contact (m^2).

A 1 impact characteristic (continuous data) by dichotomous outcome (bruise or no bruise) binary logistic regression was calculated (SPSS statistical software v15). Logistic regression was run on each individual impact characteristic to see if (a) statistically significant ($p \leq 0.05$) changes in -2 log likelihood ratio test existed when a variable was added to the model and (b) if the Hosmer-Lemshow goodness of fit test was insignificant ($p \geq 0.05$) indicating that the model prediction does not significantly differ from the observed. The p-value mentioned above is a calculated number used during statistical significance testing and is the probability of obtaining a result assuming that the null hypothesis is true (i.e. no difference exists between various conditions). The *lower* the p-value, the *less* likely the result is if the null hypothesis is true, and consequently the *more* "significant" the result is, in the sense of statistical significance. The null hypothesis is rejected when the p-value is less than 0.05. This corresponds to a 5% chance of rejecting the null hypothesis when it is actually true or a 95% confidence level that the findings are in fact significant.

The calculated impact characteristics showing significant -2 log likelihood ratio and non-significant Hosmer-Lemshow goodness of fit test between the two categories (bruise/no bruise) were then further analyzed by indicating the magnitudes of the chosen impact characteristics that would predict contusion threshold. Threshold in this case

Trial #	Location	Peak force (N)	Ink Area (m^2)	Peak pressure (kPa)	Force impulse (N*s)	Pressure impulse (kPa*s)	Displacement (m)	Tissue stiffness (N/m)	Impact velocity (m/s)	F*d energy (J)	Energy absorbed (J)	Energy density (J/m^2)	Bruise ($Y = 1$; $N = 0$)
1	Low shin	714	0.00016	4540	5.4	34.3	0.008	89250	0.7	0.1	7.9	50868	1
2	Mid shin	433	0.00021	2080	5	24	0.015	28867	1.3	1.9	6.1	38430	1
3	High shin	342	0.00020	1720	2.6	13.1	0.011	31091	1.1	0.8	7.2	40234	1
4	Low calf	825	0.00045	1820	5.8	12.8	0.038	21711	2.5	5	3	17648	0
5	Mid calf	571	0.00055	1040	5.8	10.6	0.032	17844	2.3	3.7	4.3	14571	0
6	High calf	507	0.00062	820	5.8	9.4	0.031	16355	1.2	1.8	6.2	12939	0
7	Low calf	731	0.00044	1660	5.5	12.5	0.036	20306	1.7	0.7	10.6	26115	1
8	Mid calf	532	0.00051	1040	6.5	12.7	0.032	16625	1.5	1.1	10.2	22481	1
9	High calf	460	0.00068	680	5.1	7.5	0.036	12778	1.3	0.5	10.8	17000	1
10	Low shin	874	0.00016	5560	4.8	30.5	0.017	51412	1.3	2.3	9	73158	1
11	Mid shin	720	0.00024	3060	4.7	20	0.02	36000	2	3.9	7.5	48875	1
12	High shin	542	0.00012	4520	6.2	51.7	0.023	23565	0.7	4.2	7.1	95904	0

Table 1: Data for all lower limb impacts and associated impact characteristic estimates.

was defined as the magnitude of the impact characteristic in which 50% of the time a bruise would occur. In order to achieve this tolerance curve, calculation of the logit was required and transformed into probability using the following equations:

$$\text{Logit}(p) = \beta_0 + \beta_1 X_1, \quad \text{Probability} = \frac{1}{1 + e^{-\text{logit}(p)}},$$

where "β_0" equals the logistic regression intercept and "β_1" equals the logistic regression coefficient for the first predicting variable (X_1).

Logistic regression seeks to use an independent variable to predict a dichotomous or binary dependent variable (bruise/no bruise). Therefore, by definition there must be a range of independent variable values, otherwise we may only see all "no-bruise" or all "bruise" for every value if a threshold of bruising is desired. This fact made it necessary to use different weights in order to ensure different impact energies that would translate to various absorbed energies, forces, displacements, and so on in tissue. Different impact locations are used since it is not possible to impact the same location without changing the single impact results and it is known that various types of tissues will react mechanically different. Hence, by using different locations we only test single impacts and vary the range of the impact parameter. The key point for impact location is that the location change is not too drastic. For example taking measurements off of the lower limb to determine mechanics at the shoulder or buttocks would not be transferrable. In this study we give the threshold for bruising on this one individual that could be generalized to almost any location on that one person's lower limb; useful information for an investigation.

3 Results

Figure 8 shows typical data collection traces from an impact trial. Data for all lower limb impacts and associated calculations are shown in Table 1. Theoretical force impulse was equal to 5.5 Ns for the 1.9 kg mass (trials 1–6) and 7.6 Ns for the 2.6 kg mass (trials 7–12). Theoretical kinetic impact energy ($KE = 0.5\,mv^2$) was equal to 8.0 J for weight one (trials 1–6) and 11.3 J for weight two (trials 7–12). The bruise characteristics (location, shape, size, and color) were logged for each trial causing a contusion (Table 2).

Trial #	Location	Shape	Size (cm)	Color
1	Low shin	Round	6×6	Dark red/violet
2	Mid shin	Round	4×4	Dark red/brown
3	High shin	Round	4×4	Brown/blue
7	Low calf	Round	2×2	Light brown/light green
8	Mid calf	Round	4×4	Light brown/light green
9	Low shin	Round	4×4	Dark red/brown
10	Mid shin	Round	3×3	Red/brown
11	High shin	Oval	3×2	Brown/blue

Table 2: Bruise characteristics for each trial causing a contusion (24 h post impact).

The results of the single continuous (impact characteristic) by two outcomes (bruise and no bruise) binary logistic regression showed that only one of the calculated impact characteristics varied significantly under the two different categories. Peak force, peak pressure, displacement, tissue stiffness, impact velocity, force impulse, pressure impulse, and energy density all did not vary significantly under the two categories ($p > 0.05$ [-2 log likelihood ratio test]; $p < 0.05$ [Hosmer-Lemshow goodness of fit test]). However, energy absorbed by the limb (p-value $= 0.004$ [-2 log likelihood ratio test]; p-value $= 0.659$ [Hosmer-Lemshow goodness of fit test]; β_1 standard error $= 1.159$) did vary significantly according to our two criteria. Figure 9 shows the probability of obtaining a contusion based on the energy absorbed by the limb for this one subject, where $\beta_0 = -10.565$ and $\beta_1 = 1.628$. Threshold was estimated by finding the magnitude of the impact characteristic (x-axis)

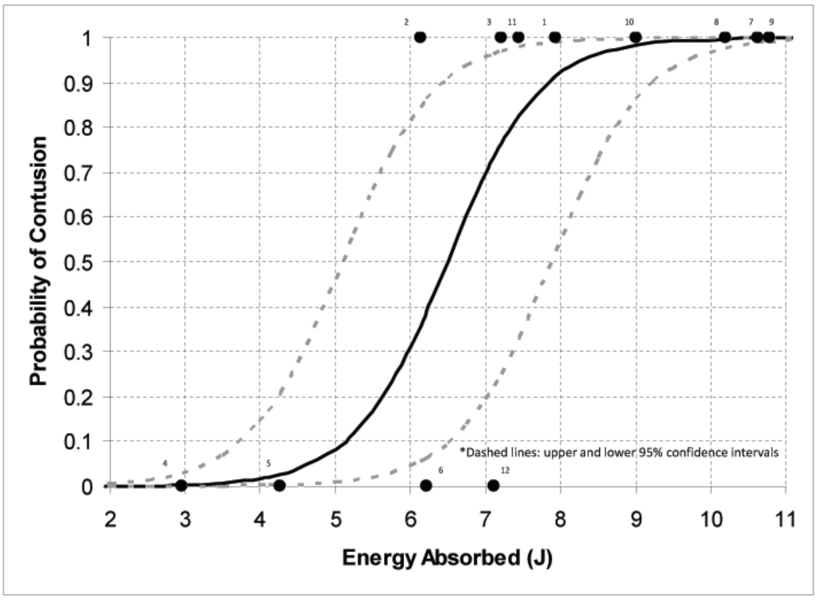


Figure 9: Probability of contusion (solid line), upper and lower 95% confidence intervals (hashed lines) [y-axis] versus limb energy absorbed [x-axis]. Binary contusion data leading to the curve is plotted (closed circles). Table 1 can be consulted to match trial numbers with parameter outcomes (#1–6 used 1.9 kg mass; #7–12 used 2.6 kg mass).

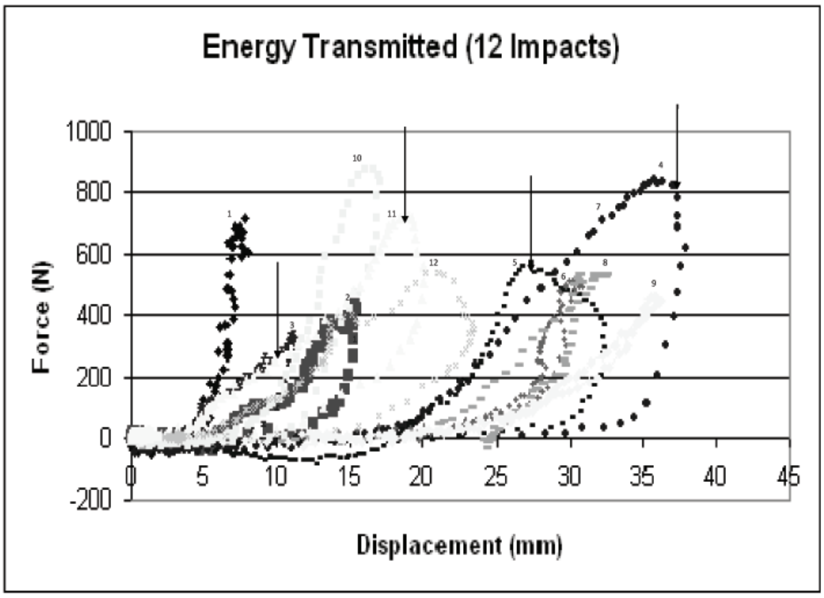
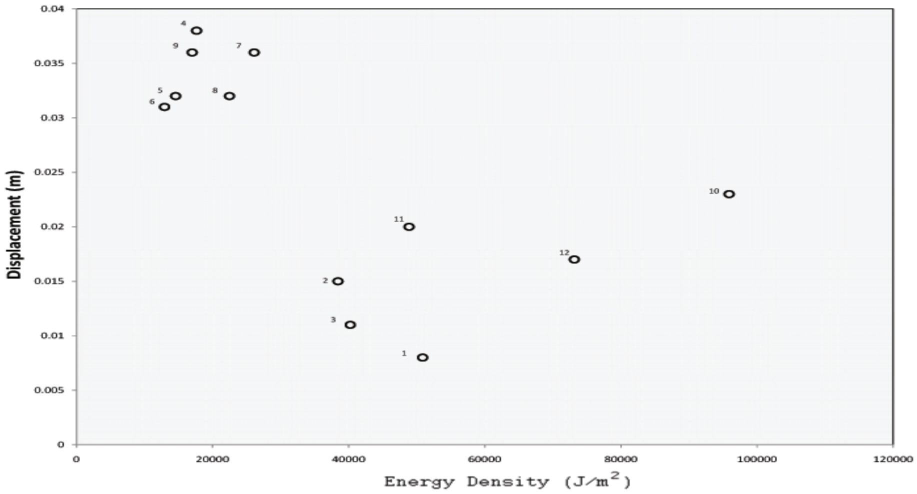


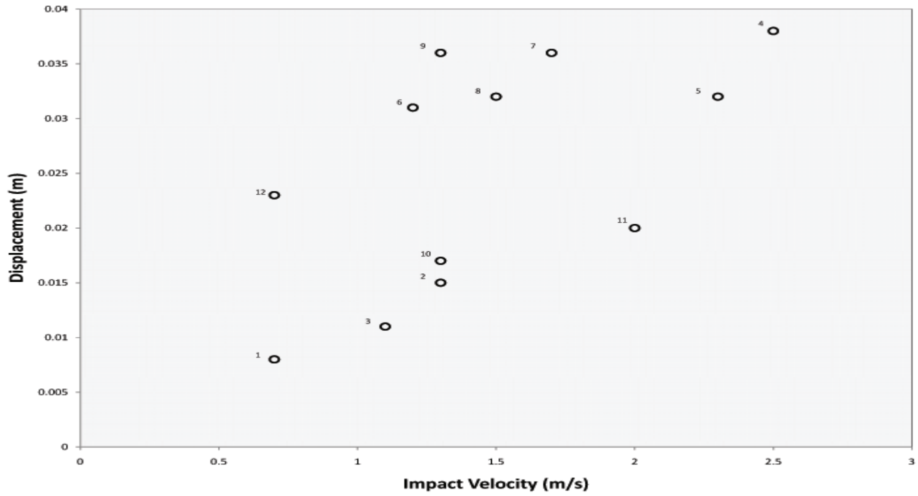
Figure 10: Force (N) versus Displacement curves (f*d) in which the energy transmitted integral was calculated. Curves indicated by an arrow did not cause a contusion. Table 1 can be consulted to match trial numbers with parameter outcomes (#1–6 used 1.9 kg mass; #7–12 used 2.6 kg mass).

at 0.5 (50%). For energy absorbed by the limb (Figure 9), a contusion threshold of 6.5 J was found. Figure 10 shows the force versus displacement curves for all twelve impacts. An arrow indicates the impacts not causing bruises.

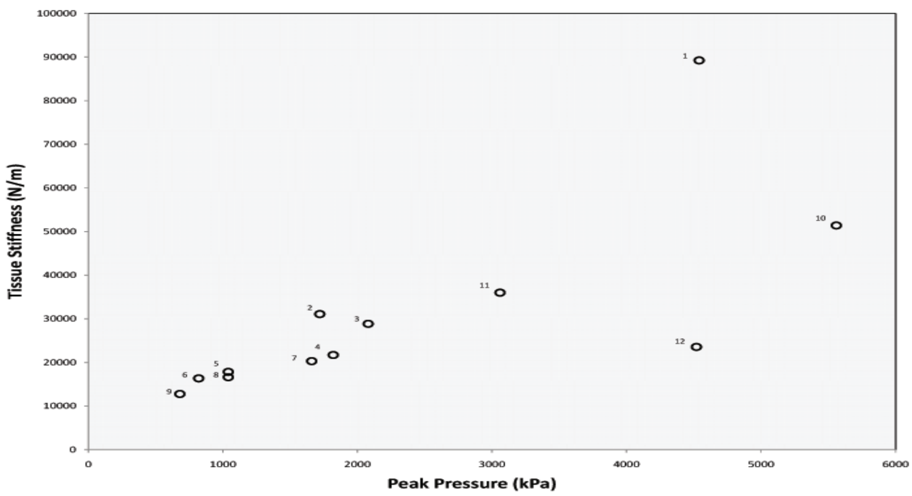
Linear correlations existed between the various impact response variables when the variables were combined and plotted. Plotting the energy density of the projectile versus peak impact displacement, we found that increasing energy density correlated with decreases in displacement (Figure 11(a)). This correlation was linear and significant ($r = -0.598$, $p < 0.041$). Plotting impact velocity versus peak impact displacement, we found that increases in displacement correlated significantly ($r = 0.585$, $p = 0.045$) with increases in impact velocity (Figure 11(b)).



(a)



(b)



(c)

Figure 11: Linear correlations between various impact response variables for all impacts were examined by plotting (a) projectile energy density vs peak impact displacement, (b) impact velocity vs peak impact displacement, and (c) peak pressure vs tissue stiffness.

Plotting peak pressure versus tissue stiffness, we found that, in general, increases in the peak pressure correlated significantly ($r = 0.728$, $p < 0.01$) with increases in tissue stiffness (Figure 11(c)).

4 Discussion

It was surprising not to find more impact characteristics varying significantly with the two categories of bruise or no bruise. A special case, energy transmitted through the limb did vary significantly but needed to be numerically transposed to attain tolerance curves that made physiological sense (positive slope). For example, as the magnitude of the energy transmitted through the limb increased, contusion probability decreased leading to a tolerance curve with a negative slope. A logical data transformation would be to plot the total energy of the projectile at the moment of impact minus the energy transferred. However, the result is no longer transferred energy but energy absorbed. We conclude that the energy transferred is a measurement necessary to estimate energy absorbed by the tissue but not a good characteristic to estimate contusion tolerance. It is important to note that the statistical significance found in Figure 9 is valid for the person and circumstances tested. While this cannot be generalized to a population, this is likely unnecessary as this method is designed to be used to investigate a crime inflicted on a single person. However, should a researcher wish to investigate a particular contusion variable it is possible to use this method using multiple subjects being impacted in a specific region once so that generalizations to a population can be made.

In this method the limb lies between the force platform and the impactor. Therefore, just as in Crisco et al. [2,3] recorded forces were transmitted through the limb as opposed to recording the force at the site of impact [2,3]. Recording force from the tip of the impactor at the skin surface might circumvent having to estimate energy absorbed by the limb as it could be then measured directly. Relating the new site of impact information to bruise outcome may also gain additional information about the striking object that caused the injury.

Several impact variables did show a trend to vary over the two contusion categories but were not statistically significant. One variable with a positive trend was tissue stiffness. It follows then, that a trend to bruise more easily may exist for stiff tissues when compared to more compliant tissues. In any case, variance introduced in the data by the variations in capillary density of the underlying tissues may also be a factor in the strength of the relationships found. Hence, whether or not a tissue is stiff or compliant there must be a critical threshold of capillary density levels present in the tissue in order for a contusion to form. For example, even though a tissue is stiff if there is a very low density of capillaries in the tissue being impacted no contusion will form.

Figure 11(a) reflects the effects of tissue stiffness, since as the trend to deform decreased, the contact area of the impactor decreased which increased the energy density. Figure 11(b) reflects the effects of tissue compliance; since velocity at the impact (defined above) was the same in all cases, increases in tissue deflection indicated a more compliant tissue and therefore allowed higher impact velocities (defined above) by delaying the peak reaction force to a greater distance effectively maintaining the initial deformation rate. Figure 11(c) reflects the relationship between tissue stiffness and peak pressure. Again, the effect of tissue stiffness is seen by reducing the area of the impactor that is allowed to contact the skin effectively increasing peak pressures. It is likely that a larger data set would find tissue stiffness a significant factor in contusion mechanics.

Implementing this technique in current crime scene reconstructions will provide the minimum required energy of the striking implement since the striking implement can have no less energy than that absorbed by the limb. However, important points remain to gain the most information possible from this technique. First, the technique must not be performed on areas of the body suspected to cause more than minor injury (more than contusion) and areas like the head & neck, genitalia, or sensitive areas of the abdomen (i.e. over liver) should not be attempted. Second, if possible the crime scene analyst should attach the known blunt impacting implement to the impactor in the orientation suspected at impact over the same limb area as the victims. This will ensure that similar tissue stresses will occur and similar capillary densities are compared. Third, if possible the actual victim should be tested once the apparatus is constructed with the striking implement on the opposite limb in the same region. This controls for the plethora of anatomical/medical/physiological/epidermal factors that affect contusion response. Fourth, our technique assumes a stationary and fixed target. If unrestricted motion of the limb is allowed, the energy of the striking implement will be higher than that estimated by this technique. However, if the arm is raised "into" the striking implement as in an attempt to protect one-self, the relative velocities between the two will be greater, increasing the total energy of the impact and reducing the necessary impact energy of the striking object to cause the documented injury. Therefore, relative motion between the limb and striking implement must be considered.

5 Conclusions

A new relatively easy-to-use method to investigate contusion mechanics in living humans has been developed. The method is designed to be used by a non-engineer that could use the technique to determine the minimum impact energy required by a striking implement to induce contusions of a particular individual during crime scene reconstructions. While we show that the experimental design and methods can be used to investigate various impact factors that affect contusion formation in a single subject, larger sample sizes are required to assess the techniques ability to be generalized if such a goal exists. However, due to the plethora of anatomical, medical and physiological variables that affect contusion formation we think it highly improbable that this technique should or could be used to compare data across the masses. Rather, we envision the method to be used as an investigative tool for individual incident reconstructions and to experimentally determine the effects of a single mechanical, anatomical, medical or physiological variable on the development of contusions. The main difficulty of course is that the experiment does cause some discomfort and minor harm to the participant, so gaining willing participants may be difficult.

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