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13. ABSTRACT (Maximum 200 words) Sufficient information is not available to determine health hazards associated with weapon recoil. This study assessed the injury response in U.S. Army Soldiers after firing a shoulder-fired weapon producing recoil energy at the upper limit authorized. Additionally, we observed injury rate and potential injury risk factors. 15 infantrymen fired 15 shots using a weapon system producing 59.09 ft-lbs of recoil energy. Markers of injury assessed pre-firing, immediately post-firing, and 24, 48, 72 and 96 hrs post-firing included subjective pain, pain-pressure threshold, bruising, range of motion, strength, a lifting task, and laboratory markers. Thermal imaging and MRI were used to assess skin temperature and edema. Data were analyzed using repeated-measures ANOVA, Pearson correlations, and descriptive statistics. 15 volunteers exhibited bruising at the anterior shoulder, and 11 reported pain with motion post-firing. 14 volunteers (93%) sustained evidence of soft tissue injury on MRI. Three (20%) sustained facial lacerations. Skin tissue temperature increased immediately post-firing and returned to baseline at 24 hr. Dominant handgrip strength had the best predictive value for injury severity on MRI. We conclude that Soldiers are at risk for soft tissue contusions and lacerations at the upper threshold of allowable recoil energy. Injury was characterized by elevated skin temperature, pain with motion, and decreased pain threshold immediately post-firing. Signal intensity changes on MRI were consistent with muscle contusion for up to 96 hrs post-firing.				
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USARIEM TECHNICAL REPORT T04-05

**SHOULDER-FIRED WEAPONS WITH HIGH RECOIL ENERGY:
QUANTIFYING INJURY AND SHOOTING PERFORMANCE**

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EXECUTIVE SUMMARY

As the U.S. Army transitions to the future, the individual Soldier may be equipped with weapon systems that produce high recoil energy (RE). Recently developed ammunition systems widen the capabilities of the M4 or M16 rifles on the modern battlefield. Initially, several of these weapon systems failed to comply with the RE limitation as specified in Test Operations Procedure (TOP) 3-2-504, *U.S. Army Safety Evaluation of Hand and Shoulder Weapons* (10). However, further scrutiny revealed the lack of scientific validity of the current recoil limitations, and the need to develop a health hazard assessment for recoil was identified. A thorough review of the literature presented in this report revealed a void of scientific evidence to serve as a basis for a health hazard assessment of recoil energy. This study is the first known attempt to quantify injury from recoil in the last 50 years and the first to investigate potential injury from exposure to the upper limits of allowable RE. Other goals were to document injury rate, identify potential injury risk factors, and assess shooter accuracy.

Fifteen volunteers completed all aspects of this 1-week repeated measures study. The independent variable was firing 15 rounds from a modified individual weapon equipped with the XM95 non-lethal munition, which produced RE of 59.09 ft-lbs. The dependent measures of range of motion (ROM), isometric shoulder and handgrip strength, pressure pain thresholds as measured by algometry, a single 45 kg box-lift, magnetic resonance imaging (MRI), skin tissue temperature as recorded by infrared imaging, and laboratory measures of creatine kinase (CK) and helical peptide activity were performed at baseline, immediately post-firing, and at 24, 48, 72 and 96 hours post-firing. Additionally, Numerical Pain Rating Scales (NPRS) were used to rate pain and recoil between shots fired and to rate pain associated with ROM, isometric strength, and the box lift. As a result of recoil, 14 of 15 volunteers (93%) sustained evidence of soft tissue injury on the MRI, while three (20%) sustained facial lacerations. Soft tissue injury on the MRI peaked at 24 hr post-firing. Skin tissue temperature increased immediately post-firing and returned to baseline at 24 hr. Pain pressure thresholds decreased immediately post-firing and returned to baseline at all sites before the end of the testing week. Statistically, but not clinically significant, changes in ROM, CK activity, and helical peptide activity were observed. Learning effects were observed in the isometric tests and box lift test. Ratings of pain and recoil between shots increased over the firing session, but no meaningful changes in NPRS were observed in the other tests. Dominant handgrip strength and, to a lesser extent, height and weight were found to have predictive value for injury severity on MRI as defined in the study.

Soldiers are at risk for injuries in the form of soft tissue contusions and lacerations at the upper threshold of allowable RE. MRI and the use of algometry proved to be the best tools to assess injury about the shoulder as a result of recoil, while dominant handgrip strength showed promise as a predictor for soft tissue contusion. Several areas of additional research have been identified. First, studies are needed to investigate the validity of all the RE ranges listed in TOP 3-2-504. Second, the effects of recoil mitigating devices and protective equipment need to be studied. Finally, studies using different firing positions and repeated exposure to high RE are needed.

INTRODUCTION

As Future Force Warrior programs are conceived and implemented, the goal of the United States Army is to increase the lethality, agility, versatility, survivability, and sustainability of its forces (8). With improved lethality, Soldiers may be required to deliver munitions of large payloads from shoulder-fired weapons. Recoil from these types of weapon systems poses potential injury and performance decrements to the Soldier. Although there have been several studies on the effects of recoil on shooter performance (13, 19, 21, 45), there has been little information published regarding injury associated with the recoil energies of shoulder-fired weapons as related to the military. Also, there have been no scientific studies to assess the validity of the current limitations imposed on shoulder-fired weaponry as found in Test Operations Procedure (TOP) 3-2-504, Safety Evaluation of Hand and Shoulder Weapons (9).

According to TOP 3-2-504, Soldiers are limited in the number of rounds they can fire per day based on the amount of recoil energy (RE) a shoulder-fired weapon produces. Recoil energy is measured in foot-pounds (ft-lbs) and is a function of the weight of the weapon, weight of the propellant, weight of the round, and muzzle velocity. Unlimited firing is permitted on weapons with less than 15 ft-lbs of RE; firing 200 rounds per day and per man is permitted on weapons with RE of 15 to 30 ft-lbs; firing 100 rounds per day and per man is permitted on those weapons with RE of 30 to 45 ft-lbs; twenty-five rounds per day and per man is permitted on weapons with RE of 45 to 60 ft-lbs; no firing is permitted on weapons that exceed 60 ft-lbs of RE (9). Again, a search of the literature did not produce the origins of these limitations, and no standard for determining tolerable recoil levels has been established scientifically (5, 50).

Although the effects of recoil can have a negative impact on the shooting performance of a Soldier firing a weapon system or, if the recoil energy exceeds 60 ft-lbs, can prevent a weapon from being field tested, the lack of evidence for tolerable recoil is surprising considering the frequent use of shoulder-fired weaponry both in the military and among competitive sport shooters and hunters. Recently, the current limiting standard of 60 ft-lbs has come under scrutiny, as the recoil energy levels of several newer proposed weapon systems have exceeded this limit. Examples of newer high-recoil systems are the M4 Carbine firing the XM95 non-lethal munition, and the first design of the Rifle Launched Entry Munition (RLEM) fired from the M16A2 rifle. The M4 Carbine firing the XM95 non-lethal munition produced 69.2 ft-lbs of recoil energy, while the first design of the RLEM produced 101.6 ft-lbs of recoil energy (44). Modifications of the RLEM lowered the recoil energy of the system to 58.94 ft-lbs, just below the current threshold of 60 ft-lbs (44). Hence, recent decisions concerning the field testing of new weapon systems and the subsequent modifications of several of those weapon systems have been based on standards of recoil energy for which the origins are unclear.

This paper reports results from a study designed to address this void of scientific knowledge on which weapon recoil thresholds were set. First, an overview of recoil and findings and direction of past research on the effects of recoil is presented. Next, injury information that has been presented in the literature is reviewed. Finally, research

results are presented from a recent collaborative study involving the United States Research Institute of Environmental Medicine (USARIEM), Natick, MA; the Army Research Laboratory (ARL), Aberdeen Proving Ground, MD; and the Walter Reed Army Medical Center (WRAMC), Washington D.C., concerning injury and shooter performance while firing a shoulder-fired weapon that produces the maximum allowable recoil energy.

OVERVIEW OF RECOIL

Recoil is the reactive force directed backward towards the firer once the weapon has been fired. This reactive force is a function “of the effective mass and imparted velocities of the weapon, the temporal and spatial distribution of the impact forces and the velocities and masses of the projectile, powder charge, expanding gases, and the presence or absence of flash hiders, muzzle brakes, etc. ...” This force is governed by Newton’s Third Law of Motion, which states that for every action there is an equal and opposite reaction (50). The recoil energy equation is given in Appendix A. During weapon firing this opposite reaction to the projectile and propellant gases leaving the barrel of the rifle is the backward movement of the rifle into the shooter’s shoulder (50). Table 1 illustrates several recoil parameters of current weapons (44).

Table 1. Recoil Parameters of Several Current Shoulder-fired Weapons.

Weapon System	Ammunition	Recoil Energy Ft-lbs (joules)	Recoil Velocity ft/sec (m/sec)	Recoil Impulse Lbs/sec (kg sec)
M16A2	5.56 mm, M855	3.3 (4.5)	5.04 (1.54)	1.38 (0.63)
M24 SWS	7.62 mm, M118	9.2 (12.5)	6.99 (2.13)	2.85 (1.29)
Winchester 1200	12 gauge 2.75- 00	28.0 (38.0)	15.90 (4.85)	3.52 (1.60)
M16A2	XM95, Non- Lethal	57.8 (78.4)	21.67 (6.61)	5.82 (2.64)
M16A2	RLEM	58.9 (79.9)	24.43 (7.45)	5.68 (2.58)

There are three components of recoil (recoil impulse, recoil energy, and recoil velocity) that are responsible for providing the “kick” associated with firing a weapon (21, 50). Recoil impulse is measured in lbs/sec; recoil energy is measured in ft-lbs; and recoil velocity is measured in ft/sec. There is some controversy over what parameters should be used in determining the effects of recoil and in setting the standards for recoil. Harper and colleagues (21) reported that the role of each component in the perception of recoil is poorly understood. Although Buc (5) reported that increases in perceived recoil are directly related to free recoil velocity and free RE, he also acknowledged that other experts in the ballistics field recommended that recoil be limited based on recoil impulse. Ganem and colleagues (18) reported that the subjective ratings of recoil of various weapons were directly related to recoil impulse and peak force. Although there is no

literature to support this recommendation, The Human Engineering Laboratory at Aberdeen Proving Ground has stated that impulse may be more important than RE in determining limitations for shoulder-fired weapons, and recommended recoil impulse be limited to 3.0 lb-sec (5, 50). During their study of man-weapon reaction forces, Hutchings and Rahe (23) identified the following parameters that affect the peak forces at the shoulder during recoil: shoulder spring stiffness; the shoulder damping coefficient; the impulse of the weapon; and the effective mass of the weapon, arms, and hands of the firer. Hence, the physical characteristics of the shooter play a role in the perceived “kick” of the recoil. However, the limitations set forth by TOP 3-2-504, Safety Evaluation of Hand and Shoulder Weapons, based on recoil energy (9) do not account for physical attributes of the shooter.

Although the shooter feels the “kick” of the weapon as soon as the projectile leaves the muzzle and the expanding gases meet the atmosphere, the actual recoil force travels in a series of waves (impulses) (50). Other aspects of perceived recoil experienced by the shooter include injury to the shooter, postural imbalance as a result of the kick from the recoil, and hesitancy on the part of the shooter to squeeze the trigger (5). It has also been noted that the physical impact of the weapon against the shoulder as a result of recoil may produce tissue damage, pain, soreness, and stiffness (50). Presence of these aforementioned conditions have the potential to cause a decrease in handgrip force on the weapon and, along with increased anticipatory flinching behaviors from noise and rifle blast, may adversely affect shooter performance (21, 50). While the shooter may anticipate and prepare for the recoil of the shot, the shooter’s initial reaction to the shot is passive because of the latency between the shot and the ability of the neuromuscular system to react. This passive response occurs during the first 150-200 milliseconds (ms) of the recoil force, after which the shooter’s neuromuscular system responds (23).

RECOIL EFFECTS ON SHOOTER PERFORMANCE AND INJURY

Although there is a lack of evidence for tolerable recoil standards, the effects that recoil may have on shooter performance have been documented as early as the 1940s. In 1949, Gay (19) reported on the recoil effects of the M1 rifle firing both the ball M2 and A.P. M2 ammunition. Gay reported that under the same conditions, firing either the ball M2 ammunition or the A.P. M2 ammunition, the variations in force and velocity from man to man were relatively large (19). In 1955, Saul and Jaffe (46) reported on the effects that recoil-reducing pads had on short-term marksmanship performance. This study was limited to nine subjects firing nine rounds in each of three recoil pad conditions. The authors reported no significant differences in performance as a result of recoil pads, but failed to report the statistical power of the study.

In a different study conducted by Saul and Jaffe (45) in which RE varied by changing the type of ammunition fired, marksmanship performance was studied. Recoil energy ranged from 11.0 ft-lb to 25.5 ft-lb during the study. Saul and Jaffe (45) reported that marksmanship performance was consistent in recoil energies between 11.0 ft-lb and

19.3 ft-lb, but as the recoil energy increased from 19.3 ft-lb to 25.5 ft-lb, significant decrements in measures of marksmanship performance were observed. These marksmanship measures included point scores, precision scores, accuracy scores, and counts of missing rounds. The authors also reported that the subjects were more likely to voluntarily terminate firing during a task requiring firing of 160 rounds on each of three consecutive days when exposed to the 25.5 ft-lb recoil energy.

In a study conducted by Ganem and colleagues (18) in 1965, the authors reported that the subjective ratings of recoil of various weapons were directly related to recoil impulse and peak force. In addition, while the recoil-mitigating device they tested did reduce the amount of reported “kick” experienced, the mitigating device did not increase the probability of hitting a target, nor did it reduce the reluctance to fire a weapon. Evans (13) reported that marksmanship performance did not differ on the Multipurpose Arcade Combat Simulator (MACS), which used a demilitarized M16A1 rifle in shooters exposed to conditions with and without recoil; however, the specific recoil energy experienced by the subjects was not included in the report.

More recently, the ARL has published several reports concerning recoil and shooting performance. In a 2001 published study, Ortega, Hickey, and Harper determined shooting performance and accuracy of Soldiers firing the M16A2 and M4 rifles before and after firing five rounds of the high-recoil XM95 non-lethal munition each day for a period of 3 days (39). The authors reported no significant differences in pre- and post-aiming scores using the 25-meter mean radii as the measure, nor did they report significant differences in performance as measured by the total number of targets hit during the 40-target qualification exercise. Despite the high recoil of the M16A2 and M4 rifles equipped with the XM95 non-lethal munition, the authors attributed this lack of recoil effect on aiming and accuracy to the use of the Protective Armor System for Ground Troops (PASGT) vest, which provided protection to the shoulder area during firing.

In an earlier study conducted by ARL in 1996, Harper and colleagues (21) studied the effect of recoil from a shoulder-fired weapon on aiming accuracy and on the willingness of Soldiers to continue firing a weapon. During this study, subjects fired weapons with different recoil energies and velocities, and fired weapons with and without recoil mitigating devices. For the weapons without a recoil-mitigating device, the specific recoil energies (and velocities) tested were 25 ft-lb (11ft/sec); 25 ft-lb (15ft/sec); 34 ft-lb (15ft/sec); 34 ft-lb (20 ft/sec); and 43 ft-lb (20ft/sec), respectively. There were two test conditions of recoil energy and velocity for the weapons with a recoil-mitigating device: 34 ft-lb (15 ft/sec) and 43 ft-lb (20ft/sec), respectively. The authors made several observations.

First, the subjects who fired weapons without recoil mitigating devices fired a significantly lower number of shots compared to the subjects firing at identical recoil energy and velocity levels, but with recoil mitigating devices. Specifically, the mean number of shots fired at the recoil energy (and velocity) of 34 ft-lb (20ft/sec) in the conditions with and without a recoil-mitigating device was 47.7 and 7.4 shots,

respectively. Similar significant differences were observed for the two groups firing at the recoil energy-velocity of 43 ft-lb (20 ft/sec); the mean shots fired by the subjects in the test condition without a recoil mitigating device was 6.73 shots; whereas, the mean number of shots fired by the subjects in the condition with a recoil mitigating device was 38.80 shots. As the recoil energy and velocity increased, the number of shots fired decreased. The subjects reported that shoulder pain was the reason they stopped firing the weapon.

Second, the authors observed that the weapons without the recoil-mitigating device were bruising the subjects. This was true for even the lower recoil energy conditions. For those subjects reporting bruising, the bruises appeared shortly after firing the weapon; in fact, some subjects reported bruising within an hour after completing weapon firing.

Reported bruising during weapon testing was not limited to the study by Harper and colleagues. Saul and Jaffe (45) also reported bruising to the subjects' shoulders and reported that a higher rate of bruising existed in the higher recoil groups (19.3 ft-lbs and 25.5 ft-lb) than in the lower recoil groups (11.0 ft-lbs and 14.9 ft-lbs). Despite wearing the PASGT vest, four of the twenty subjects in the Ortega and Hickey study complained of bruising (39).

In addition to bruising, Saul and Jaffe (45) also reported that seven subjects experienced "some" redness and swelling during the course of firing. These authors also studied several other medical outcomes of the shoulder as a result of firing at different levels of recoil energy: arm-shoulder movement, arm-shoulder strength, and skin tissue differences. They did not detect any cases of decreased motion or strength about the arm and shoulder, nor did they detect any differences in skin tissue temperatures when comparing the firing shoulder with the non-firing shoulder for the different levels of recoil energy.

In addition to these reported injuries, two other published studies have reported nerve palsy as related to shoulder-fired weapons (49, 53). Although the article by Shyu Lin et al. (49) was a report on military shooters, the injuries reported were radial nerve palsies related to position of the firer and not from the effects of recoil.

Wanamaker (53) published a report containing three separate cases of injuries to recreational and competitive skeet shooters as a result of rifle recoil. Unfortunately, the specific recoil energies of the weapons involved for each of these three case studies were not reported. The first case reported by Wanamaker was that of a 43-year-old male who developed pain, numbness, and weakness after competitive skeet shooting using a 12-gauge shot gun. The patient reported that he had fired greater than 400 shots prior to developing the symptoms. Similar symptoms were reported for the second case study that involved a 76-year old man. Unlike the first case study, however, this subject reported symptoms after the first shot while firing only 11 shots with a big-game rifle. In both of these cases the symptoms resolved after 1-3 months. The third case report was that of a man who presented with progressive pain and weakness in the right shoulder

for 3 years. He reported to be an expert trap shooter and typically fired 200-400 shots per week before the symptoms forced him to stop competing. Unlike the other two case reports, this individual's symptoms did not resolve at a 1-year follow-up exam, as reported by Wanamaker.

All three case reports had abnormal electromyographic (EMG) findings at the time of their initial clinic visit. For the first case the EMG was abnormal in the deltoid, biceps, and brachioradialis of the affected arm at rest, while the EMG findings for the second case study showed abnormalities at rest and with maximal effort in the affected deltoid, bicep, and brachioradialis. For the third case study, the EMG was abnormal in the deltoid, biceps, brachioradialis and pronator teres muscles, triceps, and wrist extension, both at rest and with maximal effort. The author speculated that the rearward acceleration (recoil) may have caused a rearward or retraction movement of the clavicle, which may have pinched or trapped the upper trunk of the brachial plexus against the scalene muscles with resulting neuropathy(53).

Injuries from recoil have been reported to be the most common unintentional, non-fatal, and non-gunshot related firearm injuries treated in hospitals (22). In the first report of its kind, Hootman and colleagues characterized these, which were treated in hospital emergency departments in the United States from 1993-1996. For unintentional, non-fatal and non-gunshot related injuries, injuries from gun recoil comprised 43% (3209 cases) of injuries that occurred during recreational activities such as hunting or target practice (22). From the same category of injuries, the sites most often affected were the head, face, neck, and eye. These injuries comprised 61%, (4205 cases) of the total injuries reported. Unfortunately, the specific number of injuries from weapon recoil to the head, face, neck, and eye was not reported.

In conclusion, the reported injuries from weapon recoil have been neurological (nerve palsy), as reported by Wanamaker (53), pain, and soft tissue injuries in the form of contusions and lacerations in the case reports of military and civilian subjects (21, 22, 39, 45). Hence, military members faced with weapons of high recoil may be at increased risk of contusions to soft tissues around the shoulder, shoulder pain, and even peripheral nerve injuries about the shoulder with prolonged exposure to high recoil.

In an attempt to partially fill the void of research concerning tolerable recoil of shoulder-fired weapons and to assist the efforts of the Center for Health Promotion and Preventive Medicine (CHPPM) in their quest to develop a health hazard assessment of the same phenomenon, USARIEM, ARL, and WRAMC joined forces to conduct a research study of shoulder-fired weapons with high recoil energy. The primary purposes of this study were to assess the injury response in Soldiers after firing a shoulder-fired weapon that produces recoil energy at the upper limit of what is currently authorized for use by U.S. Army Soldiers and to assess shooting performance during the course of firing such a weapon. The data from this study will determine the most appropriate markers to use when quantifying human tissue injury response to rifle recoil. It was our objective to achieve the following:

1. Document the injury rate among a group of Soldiers firing a shoulder-fired weapon that produces recoil energy at or just below the current limit of 60 ft-lb (as defined in TOP 3-2-504).
2. Assess the efficacy of using biomarkers, clinical examination, or both, to quantify injury resulting from high recoil shoulder-fired weapons.
3. Identify potential risk factors that may predispose Soldiers to injury when firing high recoil weapons.
4. Assess shooter accuracy during use of a high recoil shoulder-fired weapon system.

METHODS

SUBJECTS

Fifteen male U.S. Army active duty and National Guard infantry Soldiers (11B) volunteered for this study. Volunteer characteristics are described in Table 2. A physician cleared all volunteers for participation prior to arrival at the study site. Exclusion criteria included upper extremity pain, history of shoulder surgery, and actively taking muscle relaxants, anti-inflammatory medications, anti-histamines, or analgesics that might interfere with the inflammatory or skeletal muscle response. Persons with contraindications to undergoing MRI were excluded (pacemakers, metal implants, claustrophobia, or inner ear transplants). A physician cleared all volunteers for participation prior to arrival at the study site. Written informed consent was obtained from each volunteer before testing. The Human Use Review Committee, USARIEM, approved this protocol. The investigators have adhered to the policies for protection of human subjects as prescribed in Army Regulation 70-25, and the research was conducted in adherence with the provisions of 45 CFR Part 46. Volunteers were compensated the sum of \$25.00 for each completed blood draw.

Table 2. Volunteer Characteristics.

Age (yrs) ^a	22±4
Height (cm) ^a	173.4 ± 6.5
Weight (kg) ^a	74.6 ± 9.8
Right hand dominant (%)	100
Right eye dominant (%)	100
Right hand shooters (%)	100
Qualified as marksman (%)	60
Qualified as sharpshooter(%)	27
Qualified as expert (%)	13
Smokers (%)	60

^a Characteristics presented as the Mean ± SD.

PROCEDURES

The study was conducted at the Human Research and Engineering Directorate's (HRED) Small Arms Shooter Performance Research Facility (SASPRF) located at Aberdeen Proving Ground, Maryland (Appendix B). For the duration of the study, volunteers were asked to abstain from alcohol and strenuous exercise, to include resistance training for the shoulders, chest, arms, back, and legs; rucksack marching; running greater than 2 miles; and performance of push-ups and pull-ups. Daily interviews were conducted to assess compliance.

On data collection Day 1, baseline measurements were collected (see Table 3), and volunteers were taken to the firing range for familiarization and briefings on the test procedures, all standing operating procedures, and safety requirements relative to the testing facility. Subjects observed weapon firing, but did not fire the weapon during this familiarization.

On Day 2, volunteers reported to the range for firing of the high recoil weapon. Each subject fired 15 rounds, which took approximately 30 min per subject. Between each shot, volunteers used the NPRS to rate the pain level and the amount of recoil they perceived for the preceding shot. Following weapon fire, measurements of the dependent variables were performed (with the exception of blood sampling), so that the first measure was taken approximately 30 min post-firing, and the last measure began approximately 2 hr post-firing. Repeated measures of the dependent variables were taken at 24, 48, 72, and 96 hr following the initial post-firing measurements, except for blood sampling, which was conducted only at 24 and 48 hr post-firing. To control for diurnal variation, baseline and repeated measures were taken at approximately the same time of day. See Table 3 for the schedule of data collection procedures.

Table 3. Data Collection Schedule.

	Data Collection Day					
	1	2	3	4	5	6
Demographic questionnaire	X					
Anthropometric measures	X					
Subjective recoil pain		X				
Subjective recoil intensity		X				
Shooting accuracy		X				
Weapon accelerometry		X				
Subjective pressure pain threshold – algometry	X	X	X	X	X	X
Subjective pain – NPRS	X	X	X	X	X	X
Bruise assessment		X	X	X	X	X
Range of motion	X	X	X	X	X	X
Grip strength	X	X	X	X	X	X
Shoulder Isometric strength	X	X	X	X	X	X
Functional box lift	X	X	X	X	X	X
Magnetic Resonance Imaging (MRI)	X	X	X	X	X	X
Thermography	X	X	X	X	X	X
Blood sampling	X		X	X		
Urine sampling	X	X	X	X	X	X

Weapon Fire Procedures

Firing Range. The SASPRF is an outdoor small arms live-firing range that is subdivided into four firing lanes. Only one lane was used for the study, with only one subject firing at a given time. The view that the shooter saw from the firing point was a flat, grassy surface that extended out to a tree line at 600 meters.

The target used at this facility was a 4-foot by 4-foot plywood panel with a 6-inch cross in the center used as the aiming point (Figure 1). For the aiming error procedure, two 1-foot squares were placed on the 4-foot square panel with their centers three feet apart and aligned horizontally with the 6-inch cross. The target panel was located 50 meters downrange and positioned so the centers of the 1-foot blocks were level with each other. The SASPRF electronically recorded shooter identification, number of rounds fired, aiming accuracy, and weapon acceleration.

Figure 1 Target used during weapon firing



Weapon System. Test volunteers fired at the 50-meter target using a hybrid individual weapon consisting of the upper receiver group of the M4 attached to the lower receiver group of the M16. This hybrid weapon was designed to achieve a recoil energy of 59.09 ft-lbs, which is the upper threshold of allowable recoil energy. The modification was necessary to negate the effect that the weight of the accelerometer and point-of-aim device had on reducing the recoil energy when a standard M16 rifle was used. Also, in order to achieve 59.09 ft-lbs of recoil energy, the Israeli blank round was used as a mechanism to discharge the munitions. The recoil velocity and recoil impulse of the hybrid weapon were 20.84 ft/sec and 5.66 lb/sec, respectively.

Subjects fired the XM95 5.56 mm Rifle Launched Non-Lethal Munition (RLNLM). The XM95 consists of a cylinder, 5 cm in diameter and 14 cm in length. Each cylinder contained 15 rubber-covered steel balls and was placed over the flash suppressor of the hybrid weapon. The payload was dispersed in a shotgun pattern and had an effective range of 30 to 80 meters. These weapon systems have been used in past research (39). Figure 2 depicts the hybrid weapon system and XM95 munition.

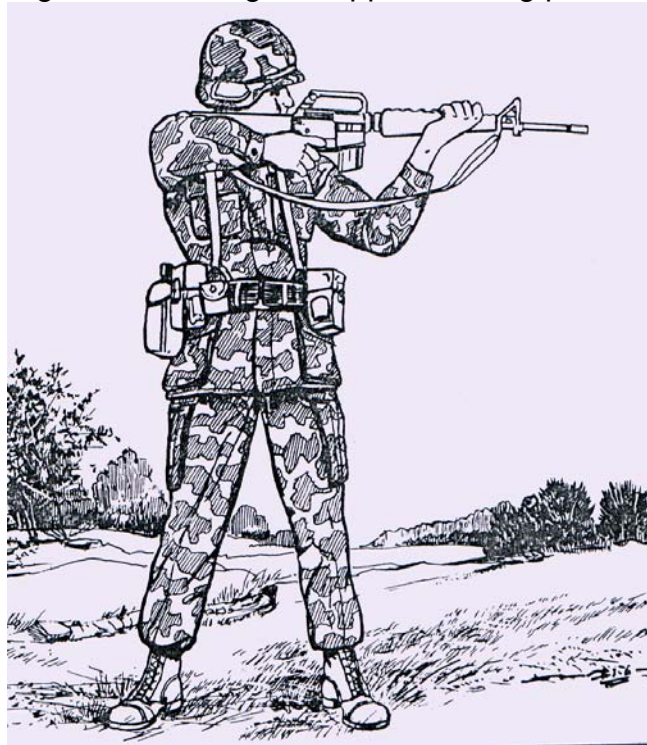
Figure 2 Weapon and munition system used in the study



Weapon Zero. To prevent the possibility of recoil injury during the zeroing process, the weapon was zeroed using a point-of-aim measuring device. Specifically, a charged couple device (CCD) was attached to the barrel to record images of where the weapon was aimed. The CCD was bore-sighted for each individual's sight picture when aimed at the target. Each subject assumed a standing, unsupported firing position (Figure 3), aimed the weapon at the target, and held this aim for 5 seconds. A series of images was collected over a 5-sec time frame, and each image was digitally analyzed to determine the locations of the 1-foot square blocks within each image. The volunteer's aiming reference or bore sight was obtained by averaging the data from these images.

Weapon Fire. Each volunteer was asked to assume a standing, unsupported firing position, and to aim at the center of the target panel. Once a good firing position and stock weld were achieved, the command "fire" was given, and the volunteer fired the weapon one time. A minimum 30-sec rest period was provided between shots. The volunteer then reassumed the firing position and was given the command "fire" a second time. This procedure was repeated for a total of 15 shots.

Figure 3 Standing, unsupported firing position



Demographic Questionnaire

Volunteers completed a demographic questionnaire (Appendix B) that included name, age, date of birth, gender, eye dominance, handedness, marksmanship qualification, and weapon-firing frequency prior to the study. A medical history section included questions on prior injury, musculoskeletal discomfort or limitations, and current medications, to assure subjects met criteria for study inclusion.

Anthropometric Measures

Height was measured using a stadiometer (Model GPM, Seritex, Inc, Carlstadt, NJ). Body weight was measured using a digital scale with subjects in the battle-dress uniform (BDU) and boots, with an adjustment 3.18 kg for uniform weight. The following additional anthropometric measures were taken using an anthropometer:

a. Functional reach – With the volunteer standing erect against a wall, right arm extended forward horizontally, and thumb and index finger pressed together, functional reach was measured as the horizontal distance from the wall to the tip of the thumb (shoulders remained in contact with the wall) (25).

b. Arm length – Vertical distance was measured from acromion to the tip of the middle finger, with the volunteer standing in the anatomical position.

c. Shoulder-elbow length – Vertical distance was measured from the acromion to the bottom of the elbow, measured with the elbow bent 90° and the lower arm horizontal.

d. Shoulder breadth – With the volunteer sitting erect with elbows flexed to right angles and held against the body, shoulder breadth across the shoulders was measured at the bulges of the deltoid muscles in the upper arms (25).

DEPENDENT MEASURES ASSESSED DURING WEAPON FIRE

Subjective Pain and Recoil Intensity

During the 30-sec rest period between each of the 15 shots, the volunteer was asked to rate both the pain and intensity of the recoil experience during the previous shot using two separate NPRS, where “0” represented no pain or no recoil and “10” represented the worse possible pain or recoil (Appendix C).

Shooting Accuracy

The HRED point-of-aim measuring device was used to assess shooting performance. The aiming error algorithm was developed internally. This CCD was attached directly to the barrel of the weapon. After bore sighting, the CCD recorded the target area where the rifle was pointed. Images were captured through the CCD and recorded on a computer. For each shot the image was captured at the point just prior to the recoil effect. Comparing this image and the position of the target blocks within that image with the volunteer’s sighting reference, the aiming error in terms of elevation and windage error was calculated. Each shooter was asked to obtain a good supported firing position, the same as if he was preparing to zero his rifle normally, and aim at the center cross on the target panel.

Weapon Accelerometry

A piezoelectric accelerometer made by Endevco (Model 222C,) was used in this study (Figure 4). The Model 222C features Endevco's Piezite[®] Type P-8 crystal element, operating in the radial shear mode, which exhibits excellent output sensitivity stability over time. A specially designed low-noise coaxial cable is supplied for error-free operation. This accelerometer was attached to the inside rear of the buttstock of the hybrid weapon. This was done so that when firing, the longitudinal axial component of the weapon's recoil could be quantified. This accelerometer was hard-wired and connected to an amplifier that recorded the rearward movement of the weapon during firing.

Figure 4. Endevco accelerometer



REPEATED PRE-POST DEPENDENT MEASURES

Subjective Pain

Algometry. A digital algometer (J Tech Medical, Salt Lake City, UT) was used to record the "pressure pain threshold" -- operationally defined as the minimum pressure that produces pain. Using the algometer to obtain pressure pain thresholds has been shown to be a valid and reliable method to assess pain (15, 31, 37, 38, 48).

Pressure pain thresholds were recorded for the mid-anterior upper arm (MUA), mid-anterior shoulder/deltoid muscle (MAS), mid-deltopectoral line (MDP), and the mid-chest/pectoral muscle (MC) for each volunteer (see Figure 5). These sites were marked with an indelible marker to ensure consistent placement of the algometer for post-firing data collection. During testing, volunteers were positioned recumbent with the arms at the side in a relaxed position. Beginning proximally and working distally, each site was tested by placing the 1.0 cm² tip of the algometer on the marked site, with increasing force applied perpendicular to the skin surface at an approximate rate of 1 kg per second. For the pressure pain threshold measure, the volunteer was instructed to give the verbal cue of "stop" at the first level of pressure they perceived as painful. The

pressure pain threshold measurements were performed at each site and were repeated three times. The mean of these three measurements was calculated for each site and recorded as the volunteer's pressure pain threshold. Volunteers were blinded to the results of all measurements.

Numerical Pain Rating Scales (NPRS). Volunteers rated the intensity of the pain felt in the shoulder region at rest, while performing the range of motion, strength, and functional tests, and between shots during the weapon fire procedure. The scale used was an eleven-point pain rating scale ranging from 0 (no pain) to 10 (worst imaginable pain) and has been shown to be a reliable, generalizable, and internally consistent measure of clinical and experimental pain sensation intensity (42, 43). The NPRS is displayed in Appendix C.

Bruise Assessment

Bruising was documented by color and size. The primary color describing the overall bruise was characterized as blue, red, yellow, or purple/black, as described in a study that assessed bruising changes over time (30). Bruises were categorized as small ($<4\text{cm}^2$), medium ($>4\text{cm}^2$ but $<25\text{cm}^2$), or large ($>25\text{cm}^2$), based on the maximum length and width of the bruise measured horizontally and vertically using a tape measure. Bruising was also documented with digital photographs.

Range of Motion

Active ranges of motion for shoulder flexion, abduction, and external rotation were measured with a standard goniometer using previously established methods (10). Three maximal efforts were recorded for each motion, and the mean score was used as the dependent measure. Inter- and intra-rater reliability coefficients for the goniometer have been shown to be .97 and .98, respectively, with measures falling within 4° within or between observers using 95% confidence intervals (35).

Strength

Isometric Handgrip Strength. Isometric handgrip strength was measured bilaterally using a hydraulic hand dynamometer (J Tech Medical, Salt Lake City, UT). After being positioned according to standardized methods (32), the volunteer gripped the dynamometer and increased the pressure applied to maximum grip strength over a period of 1-5 sec. Three successive trials were conducted with a 3-5 second rest between each trial, and the mean of the three trials used as the dependent variable. Any jerking movements or motions out of the standardized position resulted in a retrieval. Measurements were recorded in Newtons.

Shoulder Isometric Strength. Isometric shoulder strength for shoulder abduction, flexion, and external rotation was measured with a hand-held dynamometer (J Tech Medical, Salt Lake City, UT). The dynamometer was mounted on an apparatus that stabilized the device against a wall and allowed positioning to accommodate the

anthropometric characteristics of each volunteer. Measures of flexion and abduction were taken, with the volunteer standing in an anatomical neutral position with feet shoulder width apart. With the wrist in contact with the dynamometer at the level of the radial styloid process, the volunteer exerted force in the directions of shoulder flexion, then abduction. To measure external rotation strength, the volunteer flexed the elbow to 90°. The dynamometer was positioned at the dorsal aspect of the wrist, and the volunteer exerted force in the direction of external shoulder rotation. Four isometric efforts were performed for each of the three positions. The first isometric muscle effort was submaximal to assure the volunteer understood the required task. The three subsequent efforts were maximal efforts, with verbal encouragement offered. Each contraction was held for 5 sec, with the highest value recorded. A 30-sec rest period was provided between each contraction within the same arm position. A 2-min rest was provided between flexion, abduction, and external rotation measurements. The measure of maximal isometric force production has been shown to have a high test-retest reliability ($r = .0.85 - 0.99$) (54). Measurements were recorded in Newtons.

Functional Task – Box Lift

The ability to perform a functional box lift task was assessed by recording the time to complete the task and by noting the pain involved in the shoulder or upper arm during the lift. The box was positioned immediately adjacent to a platform situated at a height of 132 cm, which was designed to simulate the bed of a 5-ton truck. The box was made of metal with handles and weighed 20.3 kgs (44.8 lbs). The volunteer began in an upright standing position facing the box. On the command “go,” the volunteer lifted the box one time by the handles and placed it on the platform. Time for the lift was recorded with a stopwatch. The volunteer then reported the level of pain experienced using the NPRS. Volunteers performed only one repetition of this lift because of the potential impact that multiple lifts might have on serum CK activity.

Imaging

Magnetic Resonance Imaging (MRI). A mobile MRI unit (GE 1.5 Tesla, General Electric, Fairfield, CT) with a dedicated shoulder coil and extremity coil was used to obtain images of the shoulder and was located adjacent to the SASPRF. The volunteer was positioned supine with the shoulder positioned in neutral rotation (thumb up position) within the magnet. A scout view was then taken so that the image slices could begin at the level of the superior aspect of the acromioclavicular joint and continue distally to approximately the deltoid tuberosity of the proximal humerus. The volunteer was then placed in the dedicated extremity coil such that the coil extended as far proximally on the upper arm as could be anatomically achieved. The volunteer was then repositioned within the magnet with the shoulder in external rotation, the elbow extended, and the forearm in full supination. The image slices began proximally at the level of the coil and extended distally through the mid-biceps region. Thickness of the image slices was 5 mm with a matrix of 256 x 192 pixels. To optimize visualization of the structures of the shoulder and upper arm, both sagittal and axial T-1 weighted and short tau inversion recovery (STIR) images were acquired at a 22 cm field of view (FOV). The FOV is the

square image area that contains the object of interest. The sequence of scanning was axial and sagittal STIR scans followed by T-1 weighted axial and sagittal scans.

A board-certified radiologist specialized in neuromusculoskeletal imaging read the magnetic resonance images in terms of qualitative and quantitative changes. The qualitative reading was reported in terms of the time period in which the greatest extent of muscle edema and soft tissue reaction to the injury were visible on the images. The quantitative reading was reported as a percent of signal intensity change from baseline at the site of injury using a 2 cm² cursor over the area of injury. This 2 cm² cursor was placed over the same anatomical area of interest on the baseline MRI scans as that of the sites of injury subsequent to firing.

Thermography. Infrared imaging of the anterior aspect of both shoulders was performed prior to firing the high recoil weapon, approximately 90-min after firing and then again every 24 hr throughout the duration of the study. Images were captured with the 760 Inframetric Thermographer (Flir Systems, North Billerica, MA). According to the manufacturer, the sensitivity of this unit is 0.1°C, while accuracy is $\pm 2^\circ\text{C}$. Imaging of both shoulders was performed during each data collection period to control for any variations in daily body temperature.

All infrared images were captured in a climate-controlled building directly adjacent to the firing line. Volunteers were equilibrated to room temperature, 21.2°C, for 20 min with the upper body disrobed. Volunteers were seated in a chair with upper arms by the side, elbows bent to 90°, forearms in the neutral position (0° of pronation and supination), and hands and distal forearms resting on the thighs of each leg. Images were saved to disk and analyzed when all images could be viewed. Average temperature measurements were recorded on the shoulders of each volunteer to correspond with the bruising as noted on the digital photographs by enclosing the area of interest within a boxed cursor. These measurements were repeated ten times on ten separate occasions for each study day. The mean temperature of these ten measurements was used for data analysis.

Laboratory Tests

Blood Sampling. Three 5 ml blood samples were drawn (baseline, 24 hr and 48 hr) by venipuncture from the antecubital vein of the forearm using sterile procedures. Samples were collected in standard tubes without anticoagulants. Samples were allowed to clot at room temperature for 30 min prior to centrifugation at 3000 rpm for 10 min, allowing the serum layer to be recovered. Serum product was then separated from the initial tube and transferred to a separate blood product tube and then frozen at -80°C until analysis. Creatine kinase activity was analyzed with a photometric enzyme-based assay (Pointe Scientific Inc, Lincoln Park, MI) using a Biospec-1601 (Shimadzu Corp., Kyoto, Japan) set at wavelength 340 nm. C-reactive protein was analyzed using a chemiluminescent enzyme immunometric assay (Diagnostic Products Corporation, Los Angeles, CA) using the IMMULITE Automated Analyzer.

Urine sampling. Urine samples were collected from the volunteers at pre-firing (baseline), post-firing, 24 hr, 48 hr, 72 hr, and 96hr. All samples were collected at approximately the same time each day to control for diurnal variation and were frozen at -80°C until day of analysis. Helical peptide $\alpha 1$ residues were analyzed using a competitive enzyme immunoassay (Metra Helical Peptide EIA kit, Quidel Corp, San Diego, CA). Helical peptide results are expressed as a ratio to creatinine in order to correct for differences in urine concentration, with creatinine-corrected values expressed in $\mu\text{g}/\text{mmol}$. The intra-assay coefficient of variation (CV) ranges from 4.0% – 8.1%; and inter-assay CVs range from 5.0% – 7.0%. The biological variability (day-to-day) of helical peptide has a mean CV of 28%. The DYNEX MRX II (Dynex Technologies, Chantilly, VA) plate reader with filter 405 nm was used to analyze end-point reaction of the assay.

STATISTICAL METHODS

Sample Size Estimation/Power Analysis.

A power calculation for sample size estimation was performed a priori for the clinical measure of pressure pain threshold using an algometer. Normative values for algometry have been established for the pressure pain thresholds of various muscles to include the middle deltoid (15). Clinically meaningful differences (2 kg/cm²) have also been established (15). With a sample of 15 subjects, an alpha level of 0.05 for a one-tailed test, an estimated standard deviation of 2.4, and a minimally meaningful effect size of 2.0, the statistical power for this experimental design was 0.92. The calculation was performed with SamplePower Software, version 1.20.

Statistical Analysis.

Repeated measures analysis of variance (ANOVA) was used to analyze changes in imagery and in the dependent measures of pain, bruising, range of motion, strength, lifting, and changes in urine markers at baseline and immediately, 24, 48, 72 and 96 hr post-firing (baseline, 24, and 48 hr for blood). A repeated measures ANOVA was also used to assess shooting accuracy at 15 time points during the experimental firing procedure. Where appropriate, post hoc testing was performed using Tukey's Honestly Significantly Difference (HSD) method. Primary hypothesis tests were conducted with an alpha level of 0.05.

To derive predictors for those who might be at risk for injury during the firing of a high RE weapon, volunteers were dichotomized into a no-minimal-contused group or a moderate-contused group based on the percent change in MRI signal intensity from baseline that was observed on the day of peak qualitative injury. Anthropometric and clinical measurements were then tested for univariate association with the reference standard using independent sample *t* tests for continuous variables and chi square analysis for categorical variables. From bilateral isometric handgrip measurements, baseline dominant handgrip strength was chosen as the measurement to be analyzed because of the technique involved in weapon firing. All volunteers were right-hand

dominant and positioned the weapon into the right shoulder. In order to avoid exclusion of potential predictive variables, significance level was set to $P < 0.12$ for these preliminary, exploratory analyses. Variables that attained this significance level were retained and plotted as receiver-operating characteristic (ROC) curves. From these ROC curves, points that represent the best diagnostic accuracy were selected as the cut-off point to define a positive test result. For the potential predictive variables, specificity, sensitivity, and positive likelihood ratios were calculated. Statistical analysis was performed using Statistica Software, version 6.0 (StatSoft Inc., Tulsa, OK), SPSS software, version 12.0 (SPSS Inc., Chicago, IL), and MedCalc, version 7.2 (MedCalc Software, Mariakerke, Belgium).

Pearson R correlations were performed to determine significant correlations among shot number, maximum acceleration, perceived kick, perceived pain, horizontal aiming error, vertical aiming error, and radial aiming error.

RESULTS

For the sake of clarity and ease of reporting, the results are presented in terms of time as related to firing. The measurements reported in the results are defined as pre (pre-firing, baseline); post (immediate post-firing); and 24 hr, 48 hr, 72 hr, and 96 hr (measurements performed at 24, 48, 72, and 96 hr, respectively, after the post measurements). All 15 volunteers completed all rounds of firing and all repeated measurements. Demographic characteristics were presented in Table 2. Anthropometric measures are presented in Table 4.

Table 4. Anthropometric Measures (Mean $\pm$ SD).

Functional reach (cm)	76.3 $\pm$ 2.1
Arm length (cm)	75.9 $\pm$ 3.1
Shoulder-elbow length (cm)	35.8 $\pm$ 1.7
Shoulder breadth (cm)	44.6 $\pm$ 2.6

DEPENDENT MEASURES ASSESSED DURING WEAPON FIRE

Subjective Pain and Recoil Intensity

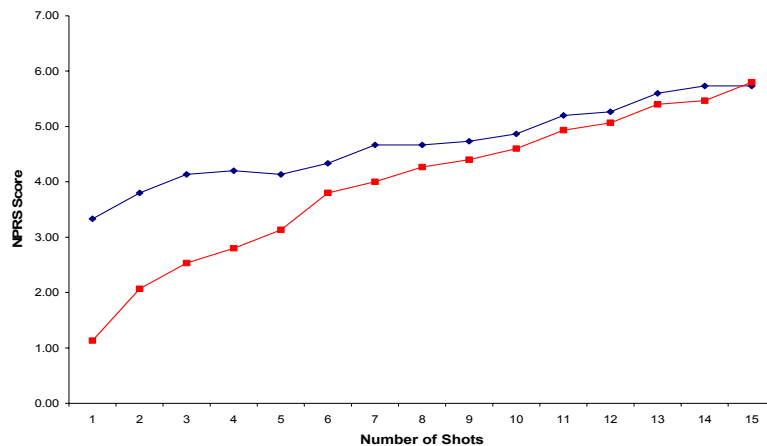
Reported pain using the NPRS was significantly higher at shots 4 through 15, as compared to the reported pain after the first shot ($F_{14, 196} = 20.002$, $p < 0.001$). Reported recoil using a similar scale (replacing the word “pain” with the word “kick”) was significantly higher at shots 7 through 15 compared to the first shot ($F_{14, 196} = 9.2614$, $p < 0.001$). Table 5 summarizes post hoc results of the subjective pain and recoil for the 15 shots. This information is depicted graphically in Figure 5.

Table 5. Subjective Recoil and Pain Scores After Each Shot (Mean $\pm$ SD).

	Recoil	Pain
Round 1	3.33 $\pm$ 1.45	1.13 $\pm$ 1.06
Round 2	3.80 $\pm$ 1.74	2.07 $\pm$ 2.05
Round 3	4.13 $\pm$ 1.60	2.53 $\pm$ 2.00
Round 4	4.20 $\pm$ 1.66	2.80 $\pm$ 2.21*
Round 5	4.13 $\pm$ 1.64	3.13 $\pm$ 2.20*
Round 6	4.33 $\pm$ 1.59	3.80 $\pm$ 2.04*
Round 7	4.67 $\pm$ 1.88*	4.00 $\pm$ 2.42*
Round 8	4.67 $\pm$ 1.80*	4.27 $\pm$ 2.23*
Round 9	4.73 $\pm$ 1.87*	4.40 $\pm$ 2.23*
Round 10	4.87 $\pm$ 2.03*	4.60 $\pm$ 2.72*
Round 11	5.20 $\pm$ 2.18*	4.93 $\pm$ 2.40*
Round 12	5.27 $\pm$ 1.94*	5.07 $\pm$ 2.69*
Round 13	5.60 $\pm$ 2.16*	5.40 $\pm$ 2.47*
Round 14	5.73 $\pm$ 2.43*	5.47 $\pm$ 2.56*
Round 15	5.73 $\pm$ 2.37*	5.80 $\pm$ 2.73*

* Denotes significant p value from Shot 1, $p < 0.01$

Figure 5. Subjective recoil and pain graph



Accelerometry

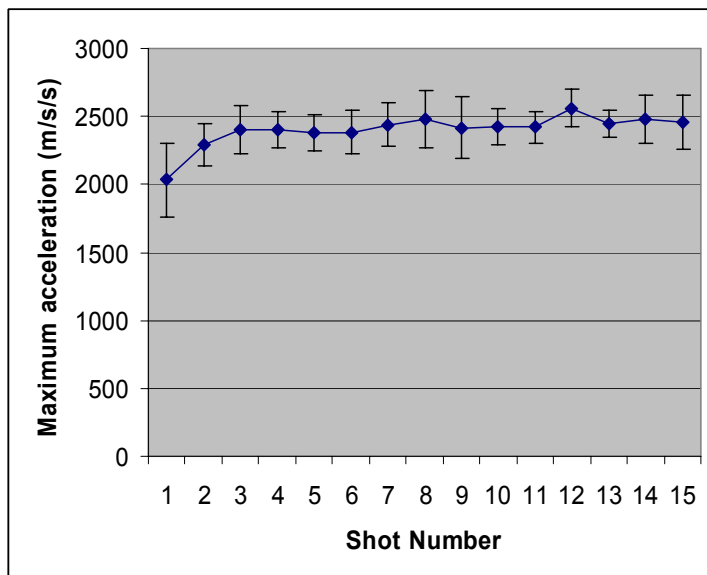
The mean maximum acceleration for this weapon was 2399.8 m/s/s, with a standard deviation of 197.2.

Shot number was significantly correlated with maximum acceleration ($R = 0.400$, $p < .001$). Table 6 provides the mean maximum acceleration for each shot fired. Figure 6 shows a graph of the mean maximum acceleration for each shot fired.

Table 6. Mean Maximum Acceleration of the Weapon for Each Shot Number.

Shot	Mean (m/s/s)	Std. Deviation
1	2031.461	270.7195
2	2289.917	151.2994
3	2403.625	179.0202
4	2404.724	131.4376
5	2381.104	132.832
6	2384.583	162.9271
7	2437.866	160.677
8	2479.248	205.7616
9	2416.626	224.0065
10	2423.401	135.4642
11	2420.105	117.9864
12	2559.710	137.0415
13	2446.106	99.11093
14	2481.628	177.1387
15	2456.726	196.541

Figure 6. Mean maximum acceleration for each shot



Shooting Accuracy

The mean horizontal aiming error for all shots at the 50 meter target was 6.7 inches with a standard deviation of 7.3 inches. The mean vertical aiming error was 8.2 inches with standard deviation of 8.6 inches.

Table 7 presents the mean and standard deviations for vertical aiming error for the volunteers (N) with vertical aiming error data. During weapon fire, unanticipated problems occurred with the transfer of aiming data from the CCD to the computer. This resulted in an inability to discern a target “miss” from missing data due to equipment failure. For this reason, we are unable to report accuracy data for all volunteers. Figure

7 presents the mean vertical aiming error of shots that had the same perceived pain ratings. For this sub-group of individuals for whom we were able to report accuracy data, reported pain associated with each shot was positively correlated with the vertical aiming error of each shot ($R = 0.343$, $p < .001$).

Figure 7. Mean vertical aiming error for shots in each perceived pain category

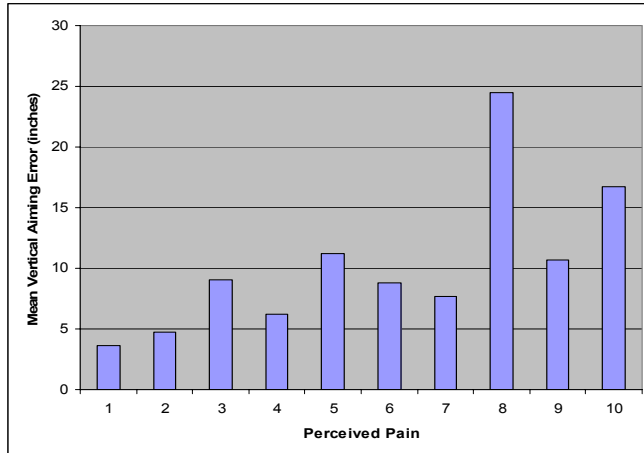


Table 7. Vertical Aiming Error by Shot Number (mean + SD)

trial	Mean	N	Std. Deviation
1	-3.4455	11	5.38133
2	-3.1800	10	12.37190
3	-2.6182	11	9.97274
4	-2.4417	12	11.79819
5	-.4750	12	16.13568
6	-2.7083	12	13.24246
7	-7.5545	11	10.05518
8	-2.7636	11	12.26208
9	1.0000	9	8.94637
10	5.9125	8	17.42776
11	7.8375	8	12.19812
12	.1000	8	12.89407
13	5.9625	8	8.76420
14	1.4000	7	6.03600
15	4.9600	5	13.99743
Total	-.5413	143	11.97204

REPEATED PRE-POST DEPENDENT MEASURES

Algometry

Compared to baseline measures, pressure pain thresholds were significantly lower at the MC ($F_{5,70} = 6.83$, $p < 0.001$); the MDP ($F_{5,70} = 9.26$, $p < 0.001$); MUA ($F_{5,70} = 5.23$, $p < 0.001$); and the MAS ($F_{5,70} = 3.39$, $p < 0.001$). Table 8 summarizes the post hoc results for the pressure pain thresholds.

Table 8. Pressure Pain Thresholds as Measured by Algometry (Mean $\pm$ SD in kg/cm^2).

	Pre	Post	24h	48h	72h	96h
MC	4.55 $\pm$ 1.85	2.84 $\pm$ 1.17 ^a	3.43 $\pm$ 1.24 ^b	3.37 $\pm$ 0.9 ^b	3.59 $\pm$ 1.11 ^b	3.90 $\pm$ 1.17
MDP	4.65 $\pm$ 1.59	3.07 $\pm$ 1.01 ^a	3.50 $\pm$ 1.22 ^b	4.07 $\pm$ 1.18	3.91 $\pm$ 1.29	4.51 $\pm$ 1.38
MUA	5.02 $\pm$ 2.38	3.33 $\pm$ 1.39 ^a	3.60 $\pm$ 1.60 ^b	3.91 $\pm$ 1.33	3.75 $\pm$ 1.25 ^b	4.41 $\pm$ 1.38
MAS	5.33 $\pm$ 2.75	3.39 $\pm$ 1.32 ^b	4.20 $\pm$ 1.82	4.49 $\pm$ 1.63	4.43 $\pm$ 1.95	4.42 $\pm$ 1.18

p-values denote tests of significance for differences from baseline

^a $p < 0.001$

^b $p < 0.05$

Bruising

Bruises were evident on all 15 volunteers. The bruising patterns in most subjects were in the large category, with only two in the medium category. These patterns were noticed immediate post-firing at the anterior shoulder (lateral pectoralis to the anterior deltoid). Three subjects had additional bruise marks: two over the biceps brachii muscle and one near the sternoclavicular region. The color of the bruises started out red-blue and turned purple, then black, and then yellow as the contusion resolved. Identifying bruise color precisely was difficult due to different skin colors of the volunteers and the multicolored bruising observed on any given day. We also observed petechiae and vertical red striae immediate post-firing, which we interpreted as chaffing from the uniform underneath the buttstock. Fourteen of the fifteen volunteers had visible injury by MRI scan. However, the inflammation area by MRI was not as large as the external contusions. Therefore, the cutaneous bruising probably represents superficial tissue damage as opposed to deep tissue inflammation. Figures 8-13 depict the cutaneous bruising pattern of one volunteer over the course of testing as recorded by digital photography.

Figure 8: Photograph of involved shoulder at baseline



Figure 9: Photograph of involved shoulder at post-firing



Figure 10: Photograph of involved shoulder at 24 hr



Figure 11: Photograph of involved shoulder at 48 hr



Figure 12: Photograph of involved shoulder at 72 hr



Figure 13: Photograph of involved shoulder at 96 hr



In addition to bruising, we observed four facial lacerations during firing as a result of the charging handle/rear sight striking the volunteer's face secondary to weapon recoil. Two volunteers sustained one laceration, while a third volunteer was struck twice on the forehead resulting in two lacerations to the area. On-site first aid was administered, and no sutures were required.

Range of Motion

There were no significant differences in shoulder flexion (Flex) or shoulder external rotation (ER) range of motion measurements. A main effect was observed for shoulder abduction (ABD) range of motion ($F_{5,70} = 8.1587$, $p < 0.001$) and NPRS scores for abduction ($F_{5,70} = 5.4539$, $p < 0.001$). NPRS scores for flexion and external rotation were not statistically different. Table 9 summarizes the post hoc results of ROM measurements and the NPRS scores observed during range of motion.

Table 9. Range of Motion Measurements as Recorded in Degrees (Mean $\pm$ SD) and NPRS Scores (Mean $\pm$ SD)

	Pre	Post	24h	48h	72h	96h
ROM						
Shoulder Abd	179 $\pm$ 6.4	174 $\pm$ 8.9*	177 $\pm$ 7.8	181 $\pm$ 6.8	181 $\pm$ 5.9	180 $\pm$ 6.6
Shoulder Flex	172 $\pm$ 8.7	170 $\pm$ 14.0	172.5 $\pm$ 10.5	174 $\pm$ 9.4	173 $\pm$ 10.3	174 $\pm$ 9.4
Shoulder ER	71 $\pm$ 14.6	71 $\pm$ 15.4	72 $\pm$ 13.6	73 $\pm$ 14.0	72 $\pm$ 15.2	71 $\pm$ 16
NPRS						
Shoulder Abd	0.40 $\pm$ 1.30	1.87 $\pm$ 2.03*	0.87 $\pm$ 1.13	0.27 $\pm$ 0.59	0.20 $\pm$ 0.56	0.20 $\pm$ 0.56
Shoulder Flex	0.33 $\pm$ 1.05	1.13 $\pm$ 1.30	0.47 $\pm$ 1.06	0.20 $\pm$ 0.77	0.27 $\pm$ 0.77	0.13 $\pm$ 0.52
Shoulder ER	0.73 $\pm$ 1.71	1.47 $\pm$ 2.00	1.00 $\pm$ 1.07	0.27 $\pm$ 0.59	0.20 $\pm$ 0.77	0.20 $\pm$ 0.77

* denotes significant difference from baseline, $p < 0.01$

Isometric Strength

Isometric strength for shoulder abduction and external rotation remained unchanged throughout the testing session. There was a significant main effect in isometric shoulder flexion ($F_{5,70} = 3.53$, $p < 0.01$). Right handgrip (RHG) and left handgrip (LHG) strength ($F_{5,70} = 4.6910$, $p < 0.001$ and $F_{5,70} = 5.1359$, $p < 0.001$, respectively) increased over the course of the testing sessions. Among the NPRS scores associated with isometric strength, the only significant main effect occurred for abduction ($F_{5,70} = 2.8886$, $p = 0.02$). Table 10 summarizes the post hoc results for the isometric and NPRS data.

Table 10. Isometric Strength as Recorded in Newtons (Mean $\pm$ SD) and NPRS Scores (Mean $\pm$ SD).

	Pre	Post	24 hr	48 hr	72 hr	96 hr
Isometric Strength						
RHG	46.6 $\pm$ 6.9	48.5 $\pm$ 8.4	48.5 $\pm$ 7.9	51.4 $\pm$ 8.9 ^a	51.3 $\pm$ 9.1 ^a	50.4 $\pm$ 7.4 ^a
LHG	47.1 $\pm$ 7.7	46.1 $\pm$ 10.0	49.3 $\pm$ 7.1 ^b	50.4 $\pm$ 7.3 ^b	50.2 $\pm$ 7.1 ^b	48.9 $\pm$ 8.7
Shoulder Abd	11.9 $\pm$ 3.0	11.0 $\pm$ 2.9	12.1 $\pm$ 2.9	12.3 $\pm$ 3.1	12.6 $\pm$ 3.3	12.2 $\pm$ 3.3
Shoulder Flex	9.1 $\pm$ 2.7	8.9 $\pm$ 2.3	9.6 $\pm$ 2.4	10.7 $\pm$ 2.1 ^c	10.4 $\pm$ 2.1	10.3 $\pm$ 2.7
Shoulder ER	11.0 $\pm$ 3.0	11.0 $\pm$ 3.0	10.9 $\pm$ 2.0	11.8 $\pm$ 1.9	12.3 $\pm$ 2.6	11.8 $\pm$ 2.1
NPRS						
RHG	0.13 $\pm$ 0.52	0.27 $\pm$ 0.59	0.20 $\pm$ 0.56	0.20 $\pm$ 0.56	0.20 $\pm$ 0.56	0.07 $\pm$ 0.26
LHG	0 $\pm$ 0	0 $\pm$ 0	0.27 $\pm$ 0.80	0.20 $\pm$ 0.56	0.20 $\pm$ 0.56	0.07 $\pm$ 0.26
Shoulder Abd	0 $\pm$ 0	1.53 $\pm$ 2.3 ^d	1.20 $\pm$ 1.90	0.93 $\pm$ 1.94	0.93 $\pm$ 1.83	0.80 $\pm$ 1.82
Shoulder Flex	0 $\pm$ 0	0.80 $\pm$ 1.78	0.33 $\pm$ 1.05	0.20 $\pm$ 0.41	0.13 $\pm$ 0.52	0.33 $\pm$ 1.29
Shoulder ER	0 $\pm$ 0	0.87 $\pm$ 1.77	0.60 $\pm$ 1.06	0.33 $\pm$ 1.29	0.33 $\pm$ 1.05	0.33 $\pm$ 1.05

^aDenotes significant difference from baseline (Pre), $p < 0.05$.

^bDenotes significant difference from Post, $p < 0.04$.

^cDenotes significant difference from Post, $p = 0.02$.

^dDenotes significant difference from baseline (Pre), $p = 0.008$.

Functional Task: Box Lift

Timed-scores of performance of the box lift improved during the week of testing ($F_{5,70} = 11.613$, $p < 0.001$). There was also a main effect for NPRS scores associated with the box lift ($F_{5,70} = 4.8645$, $p < 0.001$). Table 11 summarizes the post hoc results from the box lift times and NPRS scores.

Table 11. Box Lift Times in Seconds (Means $\pm$ SD) and NPRS Scores (Mean $\pm$ SD).

	Pre	Post	24 hr	48 hr	72 hr	96 hr
Box Lift	2.96 $\pm$ 0.38	2.79 $\pm$ 0.56	2.73 $\pm$ 0.42	2.40 $\pm$ 0.42 ^a	2.40 $\pm$ 0.36 ^a	2.32 $\pm$ 0.35 ^a
NPRS	0 $\pm$ 0	0.73 $\pm$ 1.28 ^b	0.07 $\pm$ 0.26	0 $\pm$ 0	0 $\pm$ 0	0 $\pm$ 0

^aDenotes significant difference from baseline (Pre), Post, and 24 hr, $p < 0.05$

^bDenotes significant difference from baseline (Pre) $p = 0.003$

Magnetic Resonance Imaging

Fourteen of the fifteen volunteers had visible injury on the MRI scans subsequent to firing. Of the 14 volunteers with visible injury on MRI, 12 demonstrated immediate muscle edema (evidenced during Post), while two had delayed muscle edema (evidenced at 24 and 48 hr). Of the two volunteers with delayed muscle edema, one showed barely perceptible muscle edema at 48 hr and 72 hr, with resolution at 96 hr. For the other volunteer, the muscle edema was visualized at 24 hr and persisted throughout the week of testing. On MRI and in terms of injury site, 12 subjects had injury to the anterior deltoid muscle, one had injury to the proximal biceps brachii muscle, and one had injury to the pectoralis major muscle. In addition to the muscle edema, the MRI images also demonstrated subcutaneous edema at the site of injury for the 14 volunteers with visible injury. Peak qualitative injury occurred at 24 hr in ten of the volunteers, while two peaked at Post and one peaked at 48 hr. Information of peak qualitative injury was not obtained on the volunteer with the biceps brachii contusion, because the area of contusion fell below the area that could be visualized by the dedicated shoulder coil used during scanning. Employing an extremity coil at 48 hr afforded the visualization of this particular injury, but we could not be sure of the day of peak injury. Table 12 summarizes the qualitative and quantitative reading for each subject over the course of testing.

Table 12. MRI Qualitative and Quantitative Signal Intensity Measurements.

Volunteer	Pre	Post	24 hr	48 hr	72 hr	96 hr
#1	44	99	184	140	204	227
#2 ^a	55	54	56	62	62	61
#3	56	197	193	164	216	251
#4	22	23	64	32	29	43
#5	21	26	61	31	28	33
#6 ^b	-	-	-	57	44	52
#7	44	62	125	36	48	86
#8	35	65	107	82	102	91
#9	35	99	151	140	165	161
#10	44	63	87	75	44	45
#11	44	127	174	165	174	195
#12	34	41	63	59	56	42
#13	26	35	46	44	26	26
#14 ^c	61	61	62	63	63	62
#15	36	100	88	68	57	63

Numerical values represent signal intensity at the site of injury. Bold numbers represent the day of peak injury in terms of qualitative interpretation.

^aDemonstrated barely perceptible muscle edema. Sustained subcutaneous edema, which was most pronounced at Post.

^bSustained contusion to the proximal biceps, which was not imaged until 48 hr.

^cNo soft tissue or muscle injury/edema appreciated on MRI scans.

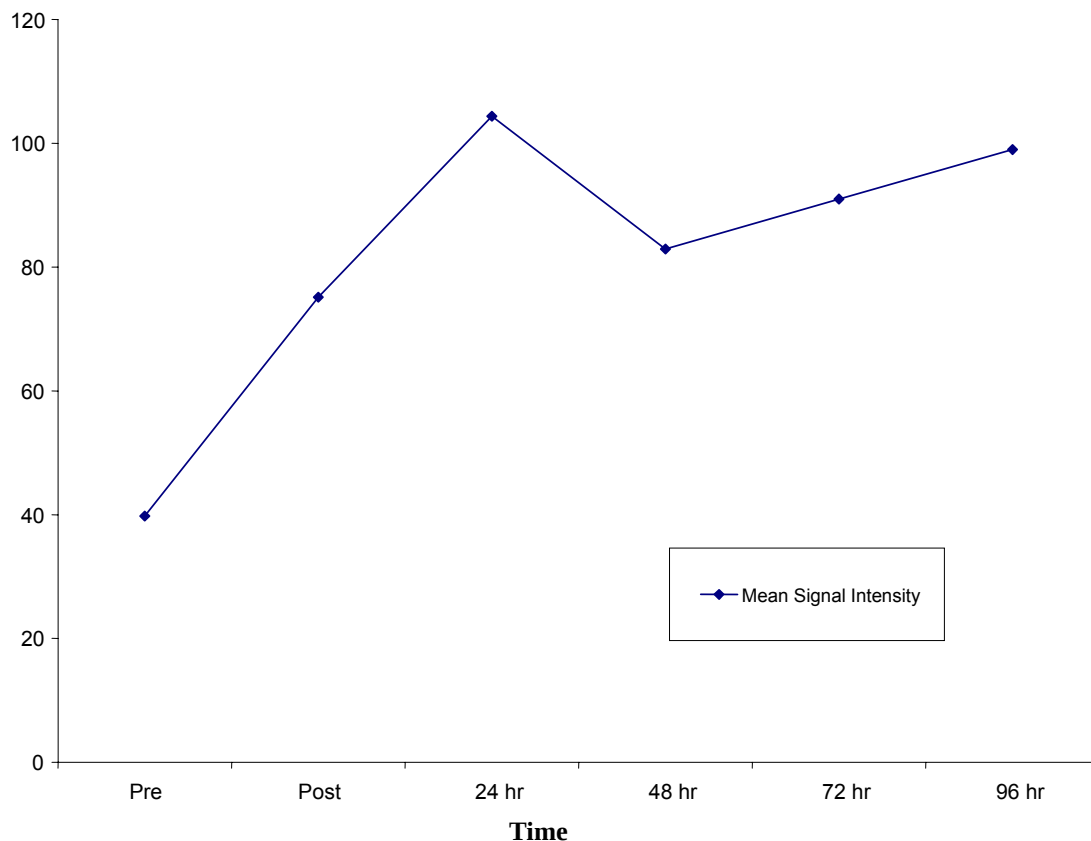
Signal intensity on the MRI scans was significantly elevated at site of injury during the testing sessions ($F_{5,65} = 9.24104$, $p < 0.001$). Table 13 summarizes the post hoc results. Figure 14 depicts signal intensity graphically.

Table 13. Signal Intensity within a 2 cm² Cursor Placed over the Area of Injury (Mean $\pm$ SD).

	Pre	Post	24 hr	48 hr	72 hr	96 hr
MRI Signal Intensity	39.79 $\pm$ 12.30	75.14 $\pm$ 46.64*	104.36 $\pm$ 51.88*	82.93 $\pm$ 48.46*	91.00 $\pm$ 68.49*	99.00 $\pm$ 76.4*

*denotes significant difference from baseline (Pre), $p < 0.05$

Figure 14. Mean signal intensity over the course of testing



The percent change in signal intensity from baseline and the day of peak qualitative injury are illustrated in Table 14. Data for peak qualitative injury were not available on one subject. For the rest of the volunteers, signal intensity percent change from baseline to the day of peak injury ranged from 1% - 318%. The mid-point of this range (159%) nicely divided the scores into a bimodal distribution and was chosen as the cut point for classifying the two groups. Nine (64%) of the volunteers were classified as having a moderate contusion, while five (36%) were classified as having no or minimal contusion. The results of the independent sample t-tests for the anthropometric and clinical measurements are presented in Table 15. There were three measurements that

demonstrated significant differences between the two groups: right-hand grip strength, height, and weight. The cut points obtained from receiver operator characteristic curve analyses and accuracy statistics are presented in Table 16. Also, accuracy statistics were computed for the presence of a positive test on all three variables, any two of the variables, and on any one of the variables. These values are presented in Table 17.

Table 14. Percent Change of MRI Signal Intensity between Baseline and Day of Peak Qualitative Injury.

Volunteer	Day of Peak Qualitative Injury	Signal Intensity Change (%)
1	24 hr	318
2	48 hr	13
3	Post	252
4	24 hr	191
5	24 hr	190
7	24 hr	184
8	24 hr	206
9	24 hr	331
10	24 hr	98
11	24 hr	295
12	24 hr	85
13	24 hr	77
14	-	1
15	Post	178

Table 15. Results of Independent Sample T-tests for Select Anthropometric and Clinical Measurements.

Variable	Group Statistics			t-test		
	Group ^a	N	Mean ($\pm$ SD)	t	df	p
Weight (kg)	1	5	80.36 ($\pm$ 14.06)	1.778	12	0.10
	2	9	71.06 ($\pm$ 5.76)			
Height (cm)	1	5	177.29 ($\pm$ 7.05)	1.821	12	0.09
	2	9	171.03 ($\pm$ 5.68)			
Pre-Handgrip Strength on Dominant Side (N)	1	5	52.82 ($\pm$ 3.77)	4.098	12	0.001
	2	9	42.34 ($\pm$ 4.94)			
Pre-Isometric Abduction (N)	1	5	12.98 ($\pm$ 3.30)	0.709	12	0.49
	2	9	11.90 ($\pm$ 2.39)			
Pre-Isometric Flexion (N)	1	5	8.02 ($\pm$ 2.64)	-1.529	12	0.15
	2	9	10.13 ($\pm$ 2.39)			
Pre-Isometric ER (N)	1	5	11.40 ($\pm$ 3.17)	0.036	12	0.97
	2	9	11.34 ($\pm$ 2.60)			
Arm Length (cm)	1	5	77.54 ($\pm$ 3.41)	1.614	12	0.13
	2	9	74.83 ($\pm$ 2.78)			
Shoulder-elbow Length (cm)	1	5	36.50 ($\pm$ 1.10)	1.244	12	0.24
	2	9	35.32 ($\pm$ 1.93)			
Shoulder Breadth (cm)	1	5	43.84 ($\pm$ 3.25)	-0.522	12	0.61
	2	9	44.56 ($\pm$ 1.95)			
Functional Reach (cm)	1	5	76.38 ($\pm$ 2.70)	0.123	12	0.90
	2	9	76.22 ($\pm$ 2.06)			
Bruise Area at Post (cm ²)	1	5	64.58 ($\pm$ 49.24)	-0.452	12	0.65
	2	9	72.24 ($\pm$ 13.14)			
Algometry of MDP Post/Pre Difference	1	5	2.06 ($\pm$ 1.03)	1.285	12	0.22
	2	9	1.46 ($\pm$ 0.72)			
Difference of Tissue Temperature, Post/Pre ($^{\circ}$ C)	1	5	1.28 ($\pm$ 0.95)	0.165	12	0.87
	2	9	1.22 ($\pm$ 0.32)			
Creatine Kinase Difference 24h- Post (U-L ⁻¹)	1	5	55.66 ($\pm$ 68.75)	0.724	12	0.48
	2	9	32.52 ($\pm$ 50.64)			
Helical peptide Difference Post-Pre (μ g/mmol)	1	5	36.07 ($\pm$ 34.02)	-0.926	12	0.37
	2	9	67.36 ($\pm$ 70.20)			
Helical Peptide Difference 24 hr-Pre (μ g/mmol)	1	5	13.35 ($\pm$ 28.83)	-0.476	12	0.64
	2	9	29.06 ($\pm$ 69.56)			

^aGroup Designees are 1, No/Minimal Signal Intensity Change (<159%) and 2, Moderate Signal Intensity Change ($\geq$ 159%).

Table 16. Accuracy Statistics for Weight, Height, and Dominant Baseline Handgrip Strength for Predicting Moderate Contusions (Increased Signal Intensity).

Variable (cut point)	Sensitivity	Specificity	Positive Likelihood Ratio (95% Confidence Intervals)	Post-test Probability
Weight ($\leq$ 79.55kg)	1.00	.60	2.50 (infinity, infinity)	82%
Height ($\leq$ 173.72 cm)	0.67	.80	3.33 (0.86, 19.07)	86%
Handgrip ($\leq$ 49 kg m/s ²)	1.0	0.80	5.00 (1.60, 27.61)	90%

Table 17. Accuracy Statistics for the Presence of a Positive Test Result for all Three Predictors (Handgrip Strength, Height, Weight), any two of the Predictors, and any one of the Predictors

Positive result on:	Sensitivity	Specificity	Positive Likelihood Ratio (95% Confidence Intervals)	Post-test Probability
All Three Tests	0.55	.92	6.60 (infinity, infinity)	92%
Any Two Tests	0.95	0.75	5.00 (1.60, 27.61)	90%
Any One Test	0.89	0.40	1.48 (0.80, 3.92)	70%

Thermography

The infrared imaging data represents 14 of the 15 volunteers. The images preserved on one volunteer did not represent the site of injury and were not included in the data analysis. Coefficients of variation using the ten measurements from each day were calculated and were less than 1% for each volunteer on each day.

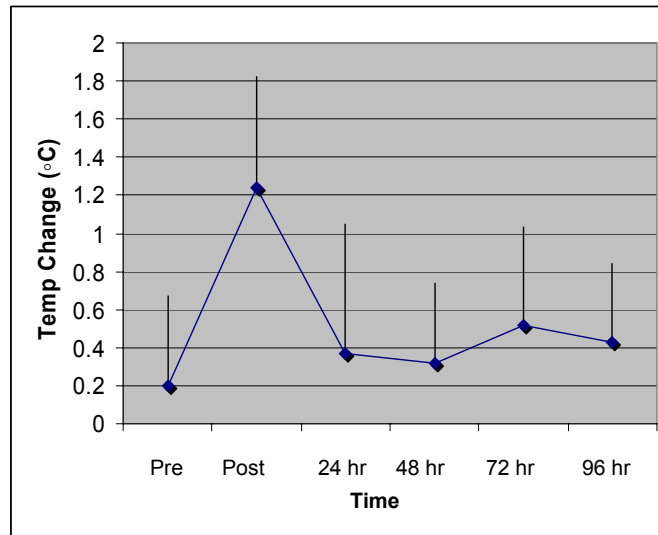
Side-to-side tissue temperature differences showed a significant elevation in temperature of the firing shoulder ($F_{5,65} = 11.613$, $p < 0.001$), as measured by infrared imaging. These observed differences were resolved by 24 hr and remained that way throughout the rest of the testing session. Table 18 summarizes the post hoc results of the side-to-side tissue temperature differences. Figure 15 depicts side-to-side tissue temperature differences over the course of testing graphically.

Table 18. Side-to-side (right – left) tissue temperature differences in °C (Mean ± SD)

	Pre	Post	24 hr	48 hr	72 hr	96 hr
Temperature Difference	0.20±0.47	1.24±0.58*	0.37±0.68	0.32±0.42	0.52±0.51	0.43±0.41

*Denotes significant difference from baseline (Pre), $p < 0.001$.

Figure 15. Tissue temperature differences over the course of testing (mean ± SD)



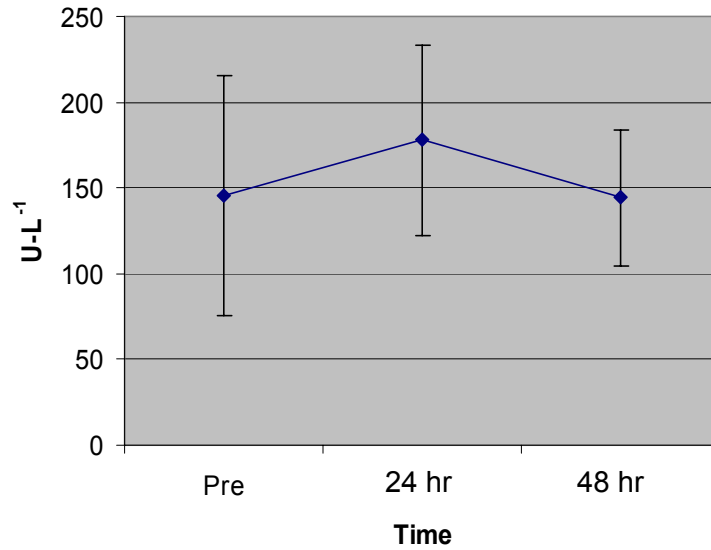
Creatine Kinase Activity

Creatine Kinase (CK) activity was analyzed at Pre, 24 hr and 48 hr. Although the results of the repeated measures ANOVA were significant for a main effect ($F_{2, 28} = 3.7073$, $p = 0.04$), post hoc tests using Tukey's HSD did not reveal a statistically significant difference between Pre, 24 hr and 48 hr. Table 19 summarizes the CK results. Figure 16 graphically depicts CK activity over the course of testing.

Table 19. CK Activity (mean ± SD, U-L⁻¹)

	Pre	24 hr	48 hr
CK Activity	145.73±69.85	177.73±55.94	144.27±39.53

Figure 16. Creatine Kinase activity over the course of testing



Helical Peptide

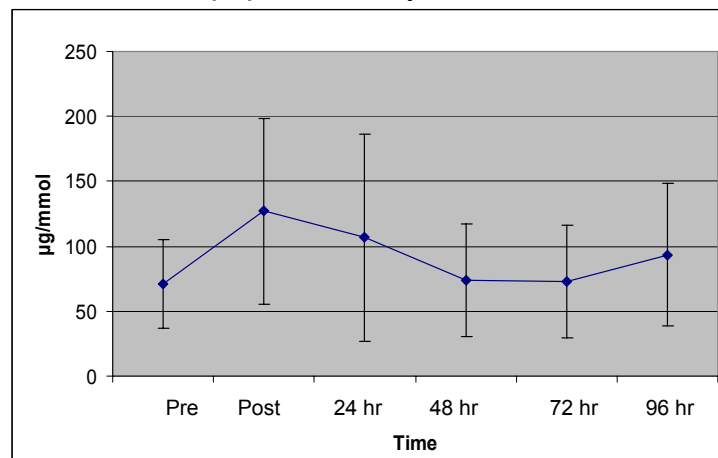
Helical peptide alpha 1 residues were elevated from baseline during the testing session ($F_{5,70} = 3.8079$, $p < 0.001$). Table 20 summarizes the post hoc results for helical peptide alpha 1 residues. Figure 17 graphically depicts helical peptide activity over the course of testing.

Table 20. Helical Peptide $\alpha 1$ Residues (Mean $\pm$ SD, $\mu\text{g}/\text{mmol}$)

	Pre	Post*	24 hr	48 hr	72 hr	96 hr
Residues	71.32 $\pm$ 33.99	126.86 $\pm$ 71.71	106.67 $\pm$ 79.63	73.83 $\pm$ 43.40	73.26 $\pm$ 34.53	93.54 $\pm$ 55.05

* Denotes significant difference from baseline (Pre), $p=0.01$

Figure 17. Helical peptide activity over the course of testing

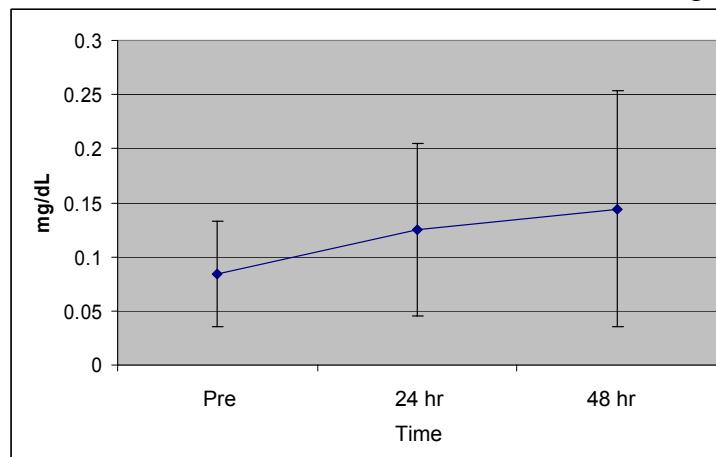


C-Reactive Protein

C-reactive protein (CRP) was analyzed at Pre, 24 hr and 48 hr. The results of the repeated measures ANOVA were not significant for a main effect ($F_{2,28} = 2.747$, $p = 0.08$). Table 21 summarizes the CRP results. Figure 18 graphically depicts CRP activity over the course of testing.

Table 21. CRP (mean $\pm$ SD, mg/dL)			
	Pre	24 hr	48 hr
CRP	0.084 $\pm$ 0.049	0.125 $\pm$ 0.08	0.144 $\pm$ 0.109

Figure 18. C-Reactive Protein over the course of testing (mg/dL)



DISCUSSION

INJURY RATES

Blunt trauma to the anterior shoulder region and minor facial lacerations were the only injuries observed during and after firing 15 rounds using a high recoil shoulder-fired weapon. Fourteen of the fifteen volunteers (93%) demonstrated evidence of injury to the anterior shoulder (deltoid muscle); proximal arm (biceps muscle); or chest (pectoralis major muscle) as determined by using MRI. In addition, 3 volunteers (20%) sustained minor facial lacerations as a result of the charging handle/rear sight striking the face from the recoil of the weapon. These injuries are consistent with the type of injuries treated in emergency rooms as a result of weapon recoil (22).

SUBJECTIVE PAIN AND RECOIL INTENSITY

Despite the blunt trauma, bruising and the incidence of facial lacerations, all fifteen volunteers fired all 15 rounds of the ammunition. The subjective pain and “kick” experienced by the volunteers increased with each round fired and was significantly higher than the first round after round 4 and 7, respectively. Thus, the recoil had a cumulative effect on pain and kick reported by the firer, which differs from past findings studying the effects of high recoil weapons. Other researchers have reported high voluntary terminations by participants exposed to the kick of high recoil energy weapons without recoil mitigating devices (21, 45). Inasmuch as the volunteers were located in the same holding area, they were all experienced infantrymen and young, healthy Soldiers, it is likely that these volunteers were highly motivated to complete the task. The concept of conformity entails modeling one’s behavior on the examples set by others with whom one interacts. Within this group there was probably social influence to avoid what may be construed as “failure” (6).

The mean maximum acceleration for the first shot fired was lower than all other shots, and there was a positive correlation between shot number and maximum acceleration. This may indicate that the Soldier initially pulled the weapon more tightly into the shoulder, as directed by the experimenters; however, acceleration was not significantly correlated with perceived pain or recoil.

SHOOTING ACCURACY

Missed shots could not be quantified due to the inability to discern between missed shots and lack of data resulting from equipment failure. Thus, while vertical aiming error was correlated with subjective pain associated with each shot, the lack of quantitative data on missed shots prevented us from drawing conclusions on how pain associated with recoil might affect a Soldier’s ability to accurately engage a down-range objective.

MRI

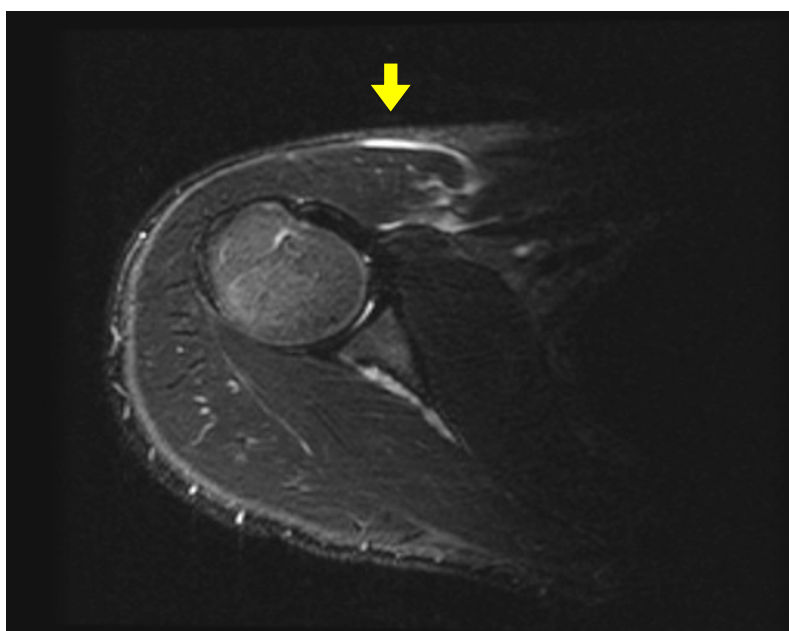
One of our goals was to identify markers and/or measurements that could be used to assess the presence and extent of injury that might occur from firing high recoil shoulder-fired weapons. MRI proved to be the most valuable tool in this regard. MRI signal intensity represents the inflammatory and edematous changes in the muscle (51), with higher intensities representing more fluid content within the muscle.

MRI is sensitive to acute and chronic changes in muscle water content (16). T-1 weighted techniques cause signal of fat to be bright and signals from areas of muscle and fluid to be lower. STIR techniques, employing an inversion pulse, suppress fat signals, allowing water and edema fluid signal intensities to be bright while fat signals appear dark (2). Axial STIR scans proved to be the best technique to observe the course of muscle contusion after exposure to recoil, which is consistent with past reports (16). Over the time series of axial STIR scans, we observed the evolution of the contusion as well as the process of a resolving contusion. Using a 2 cm² cursor over the injury site, we observed significant elevation of signal intensity at Post, 24 hr, 48 hr, 72 hr, and 96 hr, with the maximal signal intensity observed at 24 hr for most subjects. Although not statistically different, we observed the signal intensity decrease over the site of injury at 48 hr, only to rebound at 72 hr, and 96 hr, which corresponded to the qualitative and clinical observation of a resolving contusion. The rebound in signal intensity was a phenomenon of the fluid (edema) consolidating as the contusion began to resolve. Cross-sectional area of the contused areas were difficult to obtain because of the feathery appearance of the contusion, which is consistent with past descriptions of muscle contusion as viewed on MRI (51). Figures 19, 20, and 21 show the axial STIR MRI scans Pre, Post and 24 hr post-firing, and the corresponding photographs of the area during the same time period.

Figure 19. Photograph and axial STIR MRI at baseline



Figure 20. Photograph and axial STIR MRI immediately post-firing



Contused area on the MRI denoted by the arrow.

Figure 21. Photograph and axial STIR MRI at 24 hr



Again, the arrow denotes the contused area on the MRI.

POTENTIAL RISK FACTORS

Three anthropometric variables were found to have predictive value on injury severity, as ranked by signal intensity changes on the MRI scan. Moderate contusion was defined as a change in signal intensity of at least 159%. The positive likelihood ratios (PLRs) for baseline dominant handgrip strength, height, and body weight were 5.00, 3.33, and 2.50, respectively. Positive likelihood ratios indicate an increase in the probability of having the disease process or, for our study, of sustaining a moderate contusion as defined by an increase in signal intensity given a positive test result (17). As reported by Flynn and colleagues, a PLR of 1 indicates the test does not have a predictive value, whereas PLR values greater than one increase the probability of injury given a positive test result. Further, Jaeschke and colleagues (24) stated that PLR values between 2.0 and 5.0 generate small but sometimes important shifts in probability; values between 5.0 and 10.0 generate moderate shifts in Pre- to Post-test probability;

and values greater than 10.0 generate large and often conclusive changes in Pre- to Post-test probability.

From the ROC curve analyses the cut points for baseline right handgrip strength, height and weight, were 49 N, 79.54 kg, and 172.72 cm, respectively. Lower baseline right handgrip strength (<49) was found to generate moderate shifts in Pre- to Post-test probability for increased signal intensity at the site of injury on the MRI. Baseline handgrip strength produced a 90% probability of correctly classifying the type of contusion sustained in our sample based on the increase in signal intensity on the MRI scan. Height of less than or equal to 172.72 cm and weight less than or equal to 79.54 kg were found to generate a small change in Pre- to Post-test probability for increased signal intensity at the site of injury on the MRI. The probability of achieving correct classification of the injury in terms of signal intensity change on the MRI for height and weight were 86% and 82%, respectively. Although height had a slightly higher probability for correct classification than weight, the sensitivity of the height measure, which is the ability of the test to correctly predict those who would have the more severe contusion, was 67%, while the sensitivity for weight was 100%. The sensitivity for handgrip strength was also 100%. For the military leader who may employ these methods/measurements in assigning tasks, high sensitivity is important, as the goal would be to avoid a false negative (someone who had a negative screening test, yet went on to develop the more severe contusion). High sensitivity guards against false negatives.

Both right and left handgrip strength improved during the week of testing. These effects can probably be attributed to learning with right handgrip strength stabilizing at 48 hr. Because right handgrip strength was significantly greater on subsequent days, additional analyses were conducted to assess the PLR of right handgrip strength at 48 hr. From the ROC curve analysis, the cut point for the right handgrip strength at 48 hr was found to be 51.8 kg (PLR = 5.0). In pair-wise comparison between the area under the ROC curves, there were no differences between baseline handgrip strength and handgrip strength at 48 hr ($p = 0.42$). Hence, baseline right handgrip measurement and the stabilized handgrip measurement observed on Day 4 both had 90% probability of correct classification of injury.

We performed additional analyses to ascertain whether or not the presence of a positive test on all three variables, any two, or any one of the variables improved the PLR. Although, the presence of a positive test on all three measurements translated into a PLR of 6.6 and the post-test probability increased to 92%, the sensitivity was poor at 55%, and would most likely be an insufficient method to employ regarding assignment of personnel to fire high-recoil energy weapons. The presence of a positive test on any two of the measurements produced PLR and post-test probabilities identical to that of the handgrip measurements; whereas, the presence of a positive test on any one of the measurements produced a low PLR (1.48) and low post-test probability (70%). Hence, the right handgrip measurement remained the single best screening test for correct classification and sensitivity. Based on the pre-test probability of a moderate contusion

(signal intensity change > 159%) of 64% during this study, and the PLR value of 5.0 for baseline dominant handgrip strength, Soldiers with dominant handgrip strength of less than 49 kg m/s² have a 90% probability of sustaining a moderate contusion.

Although a lower right handgrip measurement and, to a lesser extent, decreased height and weight, tended to be moderate predictors for injury, as defined by sustaining a moderate contusion, a word of caution is needed. Because of the small sample size, a change in just one of the outcomes would have changed the PLR and the probability for correct classification of the test measurements. Metz (34) suggested that 100 observations are needed to derive meaningful qualitative conclusions from ROC analyses. Further, it is suggested that one case should not represent more than 2% of the observations, and as such, a minimum of 50 cases may be needed in each of the two groups (dichotomized grouping) under study (47). Also, the confidence intervals of the PLR for dominant handgrip strength (1.60-27.61), height (0.86-19.07), and weight (∞ , ∞) were very large and increased the uncertainty of the findings. However, if these measurements are borne out by further research, then they could prove useful for the commander, platoon leader, or sergeant who could assign firing tasks based on risk to the Soldier, or consider mitigation efforts for Soldiers who must fire a high-recoil weapon. Further, at least preliminarily, baseline handgrip measurement of the dominant hand proved to be as strong as the stabilized handgrip measurement for correct classification of injury. From a practical standpoint, a tool that does not have a learning curve would be desired by the commander or platoon sergeant to maximize the performance of the unit or platoon, while minimizing the risk of injury to the Soldier.

ALGOMETRY

Figure 22 depicts the marks used for placement of the algometer. All four sites showed a significant decrease in pain pressure thresholds immediately post-firing. These decreased pain pressure thresholds persisted through 72 hr and returned to baseline 96h at the MC area; through 24 hr and returned to baseline by 48 hr at the MDP area; through 72 hr at the bicep and returned to baseline at 96 hr; through Post and returned to baseline at 24 hr at the MAS. Clinically, quantification of tenderness as a result of myofascial and other musculoskeletal pain is considered abnormal if the anatomical site is 2 kg/cm² lower relative to a normal control point, such as the corresponding contralateral site (14). We observed significant reductions in pain pressure thresholds from baseline ranging from 0.96 kg to 1.71 kg. Clinically, these would fall just below what is accepted as abnormal for the presence of pathology.

Figure 22. Algometry placement sites



The indelible marker points on surface of the skin denote placement sites.

THERMOGRAPHY

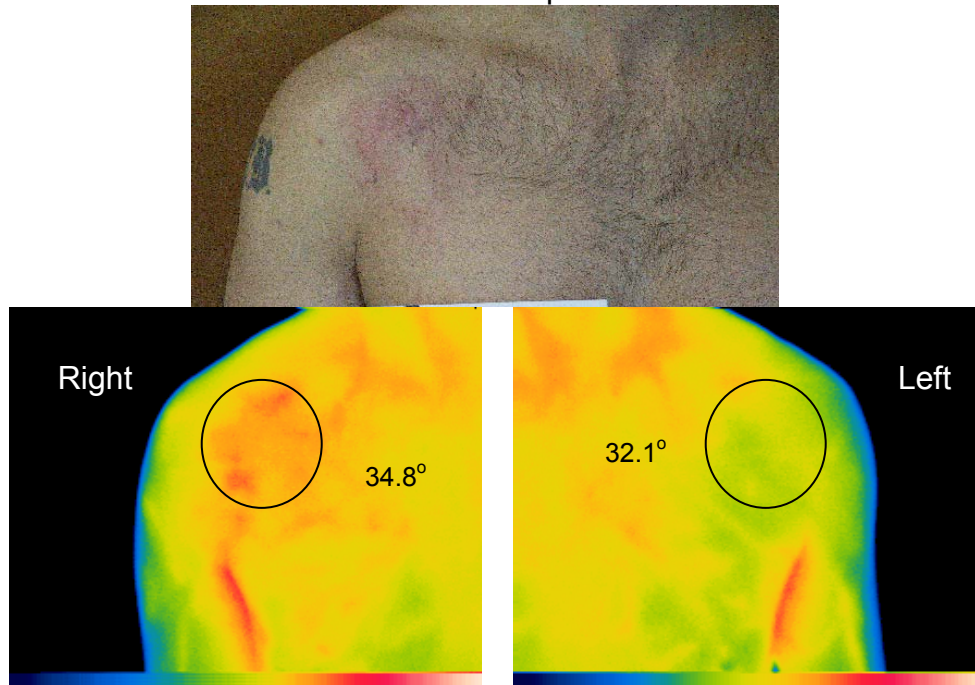
Skin tissue temperatures on the firing shoulder as measured by thermography were significantly elevated immediately after firing compared to the non-firing shoulder. Figure 9 illustrates thermal images of the injured shoulder at Post matched with the photograph of the opposite shoulder of the same volunteer on the same day. These differences had resolved by 24 h Post. Saul and Jaffe (45) reported no skin tissue temperature difference in their study on the effects of recoil. There are two possible explanations for the different findings. First, it appears that the report from Saul and Jaffe relied on a medical examiners subjective report of warmth by a palpation exam, while we studied skin temperature difference using infrared imaging as recorded by a thermography unit. Second, volunteers were exposed to different REs in the two studies. We studied the effects of recoil energies at 59.09 ft-lbs, while Saul and Jaffe studied recoil energies of less than 26 ft-lbs.

Thermography has been shown to detect small changes in skin tissue temperatures. Thermal asymmetries between opposite sides of the body are very small (0.18°C - 0.38°C), as recorded by thermography (52) and considered abnormal if differences of 0.8°C - 1.0°C are observed (11). We observed a mean increase of 1.24°C between the firing and non-firing shoulders at Post, which exceeded the minimally clinically important difference (Figure 23).

Unlike the MRI scans, which showed an evolving contusion at 24 hr, the thermal changes of the firing shoulder as compared to the non-firing shoulder had returned to baseline by 24 hr. This indicates that the skin tissue temperature elevation observed was most likely due to skin irritation at the site of placement of the weapon. Irritation may have been caused either by the recoil force or by a combination of the texture of the uniform and roughened surface of the butt of the weapon sliding across the skin surface during firing. We observed skin surface chafing of the shoulder immediately after firing during physical examination of the area. Most prior research with thermography represented sub-acute or chronic pathology (4, 33, 41), whereas the injury we observed was acute in nature and was observed to resolve or be resolving over the course of the

study. Repeated exposure to high RE over several days, however, may produce different observations for skin tissue temperatures as measured by thermography.

Figure 23. Photograph of the right shoulder and infrared images of both shoulders at post



Numbers imposed on the infrared images represent the average temperature ($^{\circ}\text{C}$) of the area of interest (contained within the ovals). The temperature scales are $27.2^{\circ}\text{C} - 37.2^{\circ}\text{C}$ for the right shoulder and $27.3^{\circ}\text{C} - 37.3^{\circ}\text{C}$ for the left shoulder.

ROM, ISOMETRIC STRENGTH, AND BOX LIFT

Although we observed a statistically significant decrease in abduction ROM immediately post-firing compared to baseline, the decrease was not clinically meaningful and does not warrant further discussion. All other ROM measurements were unchanged throughout the course of the study. There were no differences in the observed shoulder isometric strength over the course of the study except for an improvement in shoulder flexion isometric strength at 48 hr compared to Post. This result over time probably represents a learning effect. Past researchers have used repetitive box lifting (36, 40) and/or a 1-repetition maximum box lift (29) to assess occupational task performance. We observed improved timed-scores of the single sub-maximal box lift on the last 3 days compared to the first 3 days of testing, which may represent a learning effect indicating the need for a longer stabilization period for this single lift test, similar to that required for the repetitive box lift (40).

LABORATORY TESTS

Creatine Kinase

Although CK levels rose by 28% at 24 hr compared to baseline and returned to baseline levels at 48 hr, this increase was not clinically significant. Our baseline measures were consistent with past research concerning normal values (1, 3, 7, 28); however, the increase in CK at 24 hr was substantially lower than the 7-12 fold increase from baseline that has been reported by others regarding changes in CK from skeletal muscle injury (1, 3, 7, 28, 55). One possible explanation for the small elevation in CK subsequent to weapon firing was the relative small area of injury we observed. The observed elevation of CK at 24 hr and return to baseline at 48 hr did, however, mirror the observed changes of the other dependent measurements throughout the testing session.

Helical Peptide

Our observations of helical peptide were consistent with the observations for CK. Helical peptide was elevated at Post and 24 hr (44% and 33%, respectively), as compared to baseline, only to return to baseline levels by 48 hr. As observed with CK, the elevations of helical peptide we observed were not consistent with the degree of elevation (100-200%) that has been reported by past researchers regarding skeletal muscle injury (26, 27). Normal values for helical peptide have been reported to be $50.7 \pm 23.8 \mu\text{g}/\text{mmol}$ (26, 27), and our baseline measures fell at the high end of this distribution. Again, similar to the observations of CK, one possible explanation for the small release of helical peptide after exposure to the recoil was the relatively small area of injury.

C-Reactive Protein

C-Reactive Protein has been observed to be a sensitive and dependable indicator of orthopedic trauma that increases within 1-3 days post-injury (12, 20). Though we did not observe a significant rise in CRP, we did note an upward trend ($P=0.08$) over the 48 hr post injury period. All values, however, fell within the established normal range (0 – 1.0 mg/dL). A longer observation period may have been needed to observe whether a clinically significant change occurred after 48 hr.

VOLUNTEER INTERVIEWS

Interviews with each volunteer were conducted to assess opinions on firing the weapon system used during the study. Volunteers were asked about the number of shots that they thought they could continue to fire past the 15 rounds. Only 60% felt confident that they could fire 25 rounds as allowed by TOP 3-2-504. Eight subjects were asked how many rounds they felt they could fire the following day, if asked to do so. Only one of the eight felt he could fire the 25 rounds the day after the test day; whereas, the other seven gave a range of 5 to 15 rounds they felt they could fire the next day, given the same scenario.

We observed the tendency of the volunteers to rest their cheek up against the charging handle during their aiming process, which is contrary to the standardized instruction they received prior to weapon firing. Many Soldiers are taught to rest their cheek up against the charging handle during the aiming process while receiving basic marksmanship training or performing weapon qualification drills. This creates little problem when firing the standard ammunition of the individual weapon because the recoil is negligible. However, when firing munitions that produce high REs, the Soldier is at risk for getting struck in the face by the charging handle/rear sight apparatus. If the face is too close to this part of the weapon, and because of the high latency between the shot and the ability of the firer to react to the recoil (23), injury could ensue. Changing firing technique, however, violates a strong population stereotype in terms of human factors for the military population. When individual weapons are modified from their usual purpose, such as firing a munition that produces high RE, previously learned firing techniques should be considered. We also observed that the rather short length of the weapon affected the aiming technique of the Soldiers, which may have been magnified if the shorter, rear-receiver group of the M4 had been used.

CONCLUSIONS

Soldiers experience soft tissue injury in the form of contusion to their shoulders when they fire weapons equipped with munitions that produce RE at the upper level of the current acceptable standard of RE as defined in TOP 3-2-504. Again, this test operations procedure states that for RE of between 45 and 60 ft/lbs, Soldiers may fire up to 25 rounds per day. The shoulder-fired weapon in our study was a hybrid individual weapon that consisted of the lower receiver group of the M16 and the upper receiver group of the M4 and produced RE of 59.09 ft/lbs.

The volunteers in our study were young, healthy infantrymen who fired 15 rounds on a single day of the XM 95 nonlethal munition, which represents only 60% of the rounds they are authorized to fire. Ninety-three percent experienced muscle and subcutaneous contusions, and 64% of these were classified as having a moderate contusion based on the injury criteria of the MRI scans. Furthermore, 20% of the volunteers suffered a small laceration, with one volunteer sustaining two small lacerations, as a result of the rear-sight/charging handle striking the face or forehead during firing.

From our study the best tools to assess injury from shoulder-fired weapons were MRI scans performed using axial STIR technique and pressure pain thresholds as obtained by algometry. After exposure to 1 day of weapon firing, peak injury on the MRI scans occurred sometime between immediately after firing and 48-hr post firing, with 77% of the observed cases (10 of 13) of injury peaking at 24-hr post. Pressure pain thresholds were decreased at all four measurement sites immediately after firing, but had returned to baseline at all four sites by the end of the measurement period. Dominant handgrip strength before firing was a good predictor of muscle contusion, correctly discriminating those who were moderately contused from those who were not in 90% of cases for this small sample of infantrymen.

RECOMMENDATIONS

1. The current standard of 25 rounds per day per man may be too many rounds to fire, at least at the upper most level of the current upper limit of recoil energy. The standard of 45-60 ft-lbs may be too broad to consider allowing 25 rounds to be fired on an unprotected shoulder or without some other recoil-dampening device employed. If the level of injury observed in these Soldiers is deemed to be unacceptable, then the use of a recoil mitigating device is recommended. Harper and colleagues (21) have demonstrated decreased bruising and decreased voluntary firing termination among shooters firing weapons with recoil mitigating devices compared to shooters firing weapons without the devices but with identical recoil energies. An additional study may be warranted that introduces the use of a mitigating device following the same design as our study. These results could either be compared to our results, or the study could include a group that doesn't use the mitigating device.
2. This study did not assess injury and performance status for repeated exposure to high RE levels on multiple days, nor did it look at the effects of recoil in other firing positions. Studies addressing these two scenarios may be needed. Further studies may also be needed to assess the validity of the other RE limits as found in TOP 3-2-504 that define how many rounds may be fired per day, per man and; in addition to studies evaluating recoil mitigating devices, other studies may be needed to explore how the use of protective equipment (protective armor, etc.) may alter exposure to different levels of RE.
3. Any additional study should also include the measurements of height, weight, and handgrip strength in order to further validate their predictive value on injury. If these variables are indeed good predictors of injury from the recoil of shoulder-fired weapons, then commanders and other leaders within the unit could use selection criteria to choose the most appropriate members to fire high RE weapons, or to select Soldiers needing protection with recoil mitigating devices.
4. We recommend that other studies use axial STIR MRI scanning and algometry to document injury. We also recommend that future studies include more realistic functional tasks, such as weapons qualification or other common Soldier tasks.
5. If individual weapons are going to be retroactively fitted to fire munitions that produce high RE, consideration needs to be given to the human factors component of weapon design. Soldiers are taught to put their cheek up against the charging handle in basic training, but this technique may prove to be injurious if performed with high RE munitions. This would also seem to be a potential problem, as individual weapons get shorter and lighter.

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APPENDIX A

Recoil Energy Equation (From TOP 3-2-504)

$$RE = W_G/64.4 ((W_P * 1.75 + W_B) MV/ W_G * 7000)^2$$

W_G = Weight of the weapon (lb)

W_P = Weight of the propellant (grains)

W_B = Weight of the bullet (grains)

MV= Muzzle velocity of the projectile (fps or m/s)

(RE in ft-lb for conversion to SI units multiply by 1.356 to obtain joules)

APPENDIX B

Demographic Questionnaire

Please fill in the blanks with the correct information (place a question mark “?” if Unknown), or check one of the choices given with instructions.

Subject Number _____

Today's Date _____

1. Birth Date: ____/____/____ (day/month/yr)

2. Age: _____ years

3. Gender: ____ Male ____ Female (check one)

4. ____ Smoker ____ Nonsmoker (check one)

5. Duty MOS: _____

6. Time in MOS: _____

7. Rank _____ 8. Height: _____ inches 9. Weight: _____ lbs.

10. Ethnic Group (check one): ____ White ____ Black ____ Hispanic ____ Asian/Pacific Islander ____ Other

11. Educational Level (check one):
____ Less than high school graduate
____ GED
____ High school graduate
____ 1-4 years of college/technical school
____ College graduate or higher

12. Time in Service: _____ years _____ months

13. When was the last time you qualified with the M16A2 rifle? Month _____ Year _____

14. What is your current level of qualification as an M16A2 rifleman based on the Army's standard?

Marksman _____ Sharpshooter _____ Expert _____

14. Do you wear glasses or contact lenses when you shoot? Yes _____ No _____

15. Which is your dominant hand? (check one) ____ Left Hand ____ Right Hand
____ Use Both

16. Are you a left or right handed rifle shooter? (check one) _____ Left Handed
_____ Right Handed

17. Have you ever had any difficulty aiming a rifle at a target or shooting a target? (check one) ___ Yes ___ No (If yes, briefly describe the difficulty)

18. Have you experienced any of the following injuries in the past 6 months? (please circle)

- eye injury
- shoulder injury
- neck injury
- arm injury
- hand injury

(If yes, briefly describe the condition)

19. Have you ever had surgery on your neck, shoulder or arm? (check one) _____ Yes
_____ No

20. Females: is there any chance that you are pregnant? (check one) _____ Yes
_____ No

APPENDIX C

Numerical Pain and Recoil Rating Scales (Asked for Shots 1-15)

Instructions to Volunteers

You will be asked to rate any pain or discomfort in your arm or shoulder after each round you fire. You will also be asked to rate the “kick” (recoil) of each shot.

Shot:

1. Overall pain intensity/discomfort of your arm or shoulder.

NO PAIN AT ALL									WORST POSSIBLE PAIN	
O0	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10

Rate the “kick” (recoil) of this shot

NO RECOIL AT ALL									SEVERE RECOIL	
O0	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10

2. Overall pain intensity/discomfort of your arm or shoulder.

NO PAIN AT ALL									WORST POSSIBLE PAIN	
O0	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10

Rate the “kick” (recoil) of this shot

NO RECOIL AT ALL									SEVERE RECOIL	
O0	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10