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Experimental trials with Frangible Surrogate Lower Legs

J.M.L. Mah, M.P. Braid, and R.W. Fall
DRDC Suffield

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Technical Memorandum
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Abstract

Combat boot covered frangible surrogate lower legs (FSLLs) were tested at different standoffs against surrogate anti-personnel (AP) mines. The standoff had air gaps and Styrofoam™ gaps. The effect of standoff on lower limb injury was determined by examination of the FSLLs by a trauma surgeon. Differences in energy delivered were determined using a piston apparatus. In dry sand only, the greater the standoff, the less severe the injury. Standoff with air was more effective than standoff with Styrofoam™.

Résumé

Des modèles de la jambe inférieure cassable (MJIC) chaussée d'une botte de combat ont été testées à différentes distances entre la mine et la botte contre des substituts de mine terrestre anti-personelle (AP) enterrées dans du sable sec. L'espace entre la mine et la botte était formé de couches d'air ou de Styrofoam™. Un chirurgien traumatologue a examiné les blessures pour déterminer les différnces d'énergie libérée à l'aide d'un appareil à piston. La blessure était moins sévère seulement quand on augmentait la distance entre la mine et la botte dans le sable sec. L'air entre la mine et la botte était plus efficace que le Styrofoam™ pour réduire les blessures.

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Executive summary

Increasing standoff--the space between an explosive and its target--has always been considered an important technique to decrease the severity of injury to lower limbs. Standoff is incorporated into the design of many protection systems, including demining boots. This study attempts to quantitatively measure the effect that standoff has on lower limb injuries from AP blast mines.

All tests were performed using a Frangible Surrogate Lower Leg (FSLL) inserted into a standard Canadian Combat Boot. The only condition that varied was the standoff distance and the material incorporated into that distance. For an air gap, standoffs of 200 mm, 175 mm, 162.5 mm, 150 mm, 137.5 mm, and 125 mm were tested. For a Styrofoam™ gap, standoffs of 200 mm, 175 mm, and 150 mm were tested. The FSLLs were tested against a surrogate AP mine charge of 75g C4 in dry 2040 sand.

The energy delivered into the FSLL and piston was determined by measuring the displacement of a piston rig. The injury to the leg was evaluated by a trauma surgeon.

The number of trials performed here was too small to compile accurate statistics but some trends were demonstrated. Whether standoff consisted of an air gap or a Styrofoam™ spacer, the greater the standoff, the less severe the injury. When the standoff consisted of an air gap, there is a clear attenuation of the injury level for standoff values of 150 mm and more; none of the surrogate legs required an amputation when standoff exceeded that value. However, the introduction of Styrofoam™ into the standoff space altered this result —amputation could not be avoided until the standoff distance reached 200 mm.

While only air-filled or Styrofoam™-filled standoffs were tested, it appears that the addition of mass within that space is detrimental. Further investigation, where different materials of different densities are used to fill a non-varying standoff gap, would shed light on this point and could have implications for design of future protective systems. Based on these results, the most favourable condition seems to be an air gap.

There was a significant variation in severity of injury with standoff, but none of the standoff distances chosen resulted in any visible damage to the Combat Boot. This would indicate that boot damage is not necessarily an accurate predictor of lower limb injury.

The trend that a greater standoff indicates greater injury reduction may be a function of the soil used. Hlady showed that standoff was effective in sand (increasing the standoff by 50% results in an average of 60% less energy transferred to the target) but that there is no difference in the prairie soil.[4] Although the data shows that with an increased standoff there is less injury, this might not be so with other soils, so standoff tests and other testing and evaluation using a variety of soils should be examined.

Mah, J.M.L., Braid, M.P., Anderson, I.B., Fall, R.W. 2007. The Effect of Standoff on Protection Systems. DRDC Suffield TM 2007-059. Defence R&D Canada – Suffield.

Sommaire

L'augmentation de la distance entre la mine et la botte, c'est à dire l'espace entre l'explosif et sa cible, a toujours été considérée comme une technique importante pour diminuer la sévérité des blessures aux membres inférieurs. La distance mine-botte est incorporée dans la conception de beaucoup de systèmes de protection dont les bottes de déminage. Cette étude tente de mesurer quantitativement l'effet de la distance mine-botte, i.e. des mines à effet de souffle AP sur les blessures à la jambe inférieure.

Tous les essais ont été effectués au moyen des modèles de la jambe inférieure cassable (MJIC) insérée dans la Botte de combat canadienne standard. Les seules conditions ayant changé étaient la distance entre la mine et la botte et le matériau incorporé dans cette distance. On a testé les intervalles d'air à des distances de 200 mm, 175 mm, 162.5 mm, 150 mm, 137.5 mm, et 125 mm. Pour les intervalles Styrofoam®, on a testé à des distances de 200 mm, 175 mm, and 150 mm. Les MJICs étaient testées contre des charges de remplacement AP ayant des charges de 75g de C4 dans le sable sec 2040.

L'énergie transmise au MJIC et le piston a été déterminée en mesurant le déplacement du piston. La blessure à la jambe a été évaluée par un chirurgien traumatologue.

Le nombre d'essais effectués ici était trop petit pour réduire l'incertitude statistique des données, mais quelques tendances ont été démontrées. La sévérité de la blessure diminue si on augmente l'étendue de la distance entre la mine et la botte, que la distance mine-botte consiste de couches d'air ou de Styrofoam®. Il y a une nette atténuation de la sévérité de la blessure pour des valeurs de distance de sécurité de 150 mm et plus quand la distance mine-botte consiste en un intervalle d'air, i.e. aucune des jambes de remplacement n'a requis une amputation quand la distance mine-botte excédait cette valeur. L'introduction de Styrofoam® dans l'espace de sécurité a cependant altéré ce résultat, l'amputation étant inévitable à moins que la distance entre la mine et la botte n'atteigne 200 mm.

Alors que seules ont été testées les distances constituées d'air ou de Styrofoam®, il apparaît préjudiciable d'ajouter une masse à cet espace. De plus, amples études permettraient d'éclaircir ce point; des matériaux divers de différentes densités pourraient être utilisés pour emplir un intervalle de distance entre la mine et la botte invariable ce qui pourrait avoir des implications dans le concept de systèmes de protection futurs. En se basant sur ces résultats, la condition la plus favorable semble être celle de l'intervalle d'air.

Il y avait une variation importante de la sévérité des blessures avec la distance entre la mine et la botte mais aucune des distances de sécurité choisies n'a résulté en des dommages visibles à la botte de combat. Ceci semble indiquer que le dommage à la botte n'est pas nécessairement un paramètre de prédiction de blessure à la jambe inférieure.

La tendance impliquant qu'une distance entre la mine et al botte supérieure réduit d'autant plus la blessure pourrait être une fonction du sol utilisé. Hlady a démontré que la distance mine-botte était efficace dans le sable (l'augmentation de 50% de la distance mine-botte résulte en une diminution d'énergie transférée à la cible d'une valeur moyenne de 60%) mais qu'il n'y a pas de différence avec le sol de la prairie. Les données indiquent qu'une augmentation de la distance entre la mine et al botte réduit la sévérité des blessures mais ce n'est peut-être pas le cas avec d'autres sols. Il faudrait donc effectuer des tests de distance mine-botte ainsi que d'autres tests et évaluations utilisant une variété de sols.

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1. Introduction

Standoff--the space between an explosive and its target--has always been considered an extremely important concept in protection systems to decrease injury and damage to the target. It has generally been observed that when standoff is increased, the severity of injuries lessens. This study attempts to quantitatively measure the effect that standoff has on blast mine injuries specific to the lower limb.

When defining standoff for the testing and evaluation of demining footwear, the distance referred to is the space between the top of the soil and the bottom of the heel. The test parameters recommended by the NATO Test Methodologies specify that the explosive itself is usually at a 2cm depth of burial under the heel [1].

Standoff is incorporated into the design of many protection systems, including demining boots. Conventional demining boots and platform boots increase standoff. Conventional boots have thicker soles made of materials intended to absorb energy. Platform boots such as the Med-Eng Foot Protection System (FPS), the Samad Rubber Works Mine Shoe, and the Fevam America Inc. Demining Sapper Platform have both a larger standoff and an air gap.

The objective of this report is to:

1. Look at the extent to which standoff protects from blast effects for 75 grams of Composition 4 (C4) explosive surrogate anti-personnel (AP) mine

2. Look expressly at the function of standoff in reducing injury

3. Look at the difference between standoff where the space is filled with air and standoff where the same sized space is filled with foam

4. Look at the difference in energy transferred to the FSLL and piston apparatus

2. Materials and Methods

2.1 Standoff examined

All tests were performed using a Frangible Surrogate Lower Leg (FSLL) inserted into a standard Canadian Combat Boot. The FSLL has been shown to provide repeatable results for injury assessment [2]. The only condition varied was standoff. In this study, standoff will be defined as the distance between the top of the screed sand and the heel of the combat boot.

Two types of standoff tests were performed, as shown in Figure 1. The first six tests used an air gap between 125 mm and 200 mm. Three subsequent tests were done by introducing layers of Styrofoam® sheets, 100 mm wide by 300 mm long, under the combat boot. This material was selected for its light weight and low density.

The initial standoffs chosen were 200 mm, 175 mm, 150 mm, 125 mm, 100 mm, and 75 mm because the Styrofoam® used for the spacer is manufactured in 25 mm thick sheets. However, the damage at 125 mm would have resulted in an amputation, so it was felt that smaller standoffs would provide little additional information. Instead, smaller increments in standoff--137.5 and 162.5 mm--were included to offer more useful information and attempt to establish an amputation threshold for this charge size.

The height was defined by gluing layers of 25 mm Styrofoam® together and placing that "block" under a combat boot, which was then attached to the FSLL. The assembly was mounted on the piston apparatus. For standoffs that varied by 12.5 mm, measurements were made using a rigid ruler. For the air gap standoff tests, the Styrofoam® was removed before the charge was detonated.

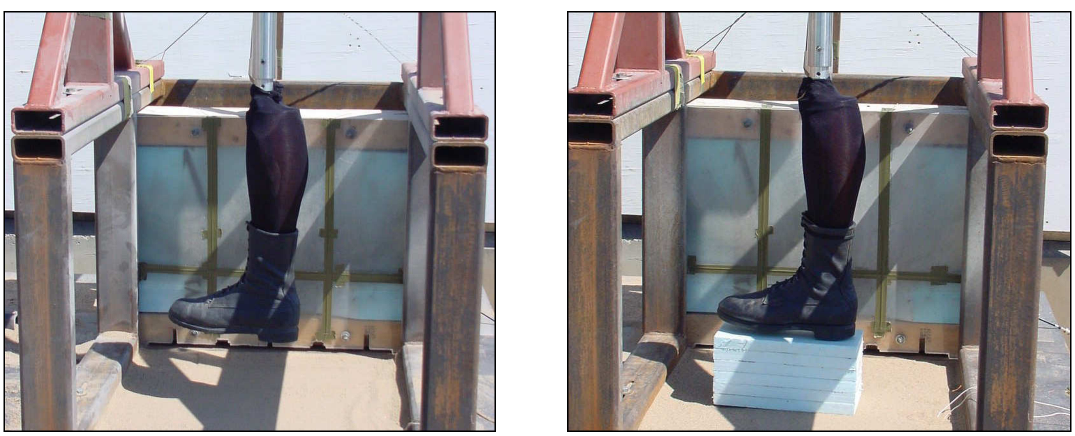

Figure 1. Setup to study the effect of standoff on the level of injury; (left) with an air gap and (right) with Styrofoam® inserted.

2.2 Frangible Surrogate Lower Leg

Nine right-legged frangible surrogate lower legs (FSLLs), developed by the Australian Defence Science and Technology Organization (DSTO) [2], were prepared for this study. The FSLL can be seen in Figure 2. All FSLLs were maintained at 4°C in a cooling unit until just prior to the test to preserve the ballistic gelatin.

Figure 2. FSLL bones (left) and with soft tissue (right); boot attached

2.3 Explosive Threat

The charge size, 75g of Composition 4 (C4), was selected to approximate an average anti-personnel (AP) mine that may be encountered in the field. The C4 was packed in Dupont Adiprene® containers, all of which had a height-to-diameter ratio of 35% based on a review of AP mine geometries. The charges were bottom initiated with RP-87 detonators.

2.4 Trial Procedure

The following technique and conditions were used to test all boots and were adopted from a NATO methodology [1] for testing personal protective equipment (PPE). Before each trial, the test boot was put on an FSLL and laced up tightly. The surrogate leg was attached to a 25kg piston shaft so that the FSLL and boot could only move linearly along the vertical shaft axis. In this vertical position, the surrogate limb is considered fully extended, according to NATO test methodology. The piston shaft was lowered to the surface of the sand to mark the location of the centre of the heel where the charge would be buried and to set the piston stop that held the boot at a 0 kg pre-load condition. The piston shaft was then raised so that the explosive charge could be buried.

The explosive charges were buried in dry 2040 sand (also referred to as number 7 sandblasting sand) that was loosely poured into a rectangular soil container, 460mm x 610mm x 460mm (depth), made of 12mm thick mild steel. A screed was used to loosely level the sand both before and after the burial of the charge. The charges were buried with 20 mm overburden at the location of the center of the heel previously marked when the piston was lowered. The decision to position the charge beneath the centre of the heel was made because that location is considered the worst case scenario in terms of delivering damage to the human lower extremity.

The piston shaft was then lowered to the piston stop. The site was cleared, instrumentation verified, a final safety check made and then the explosive charge was initiated.

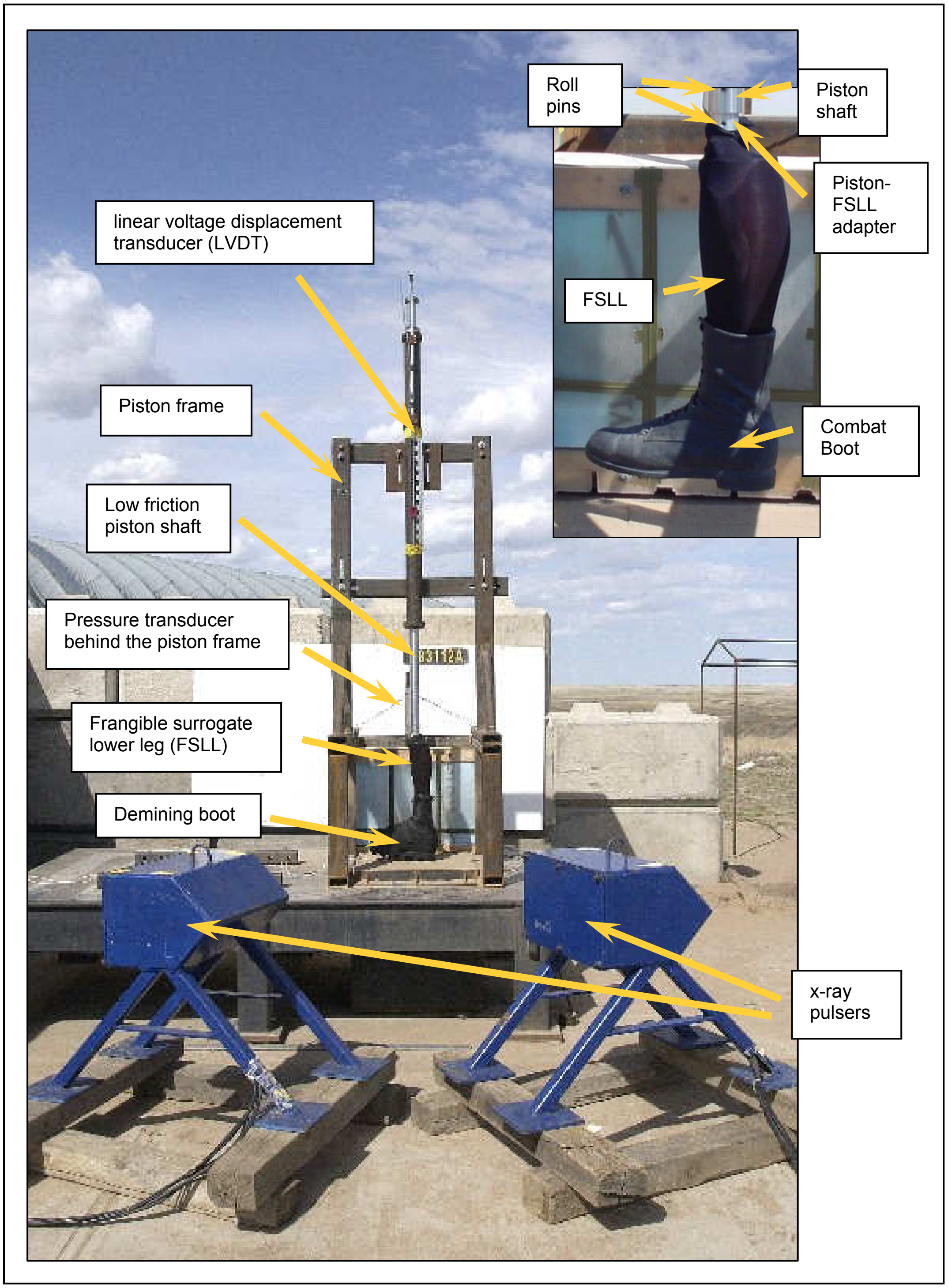

Figure 3. Piston shaft apparatus

2.5 Post Trial Medical Assessments

Dr. Colonel Ian Anderson, experienced in both civilian and military casualties, examined each FSLL, post trial. Dr. Anderson has extensive experience with both cadaver and FSL dissections. Given the resources available to the project and Dr. Anderson's background, a single medical opinion was deemed adequate.

The surgeon was blinded to the standoff distance and material. Examinations were videotaped and each dissection was documented with a series of photographs.

The specimen was examined in detail. The completeness of the specimen, perforations of the nylon mesh, evidence of contamination, joint stability, splits and defects in the gelatin, and the integrity of the surrogate bones were all noted.

After documenting all of the injuries associated with a given specimen, the surgeon summed the total of the injuries for each specimen and assigned several injury scores. The Mine Trauma Score (MTS) was used to evaluate the effectiveness of standoff as recommended in other reports [3]. A salvegeable leg is considered protected while a leg that requires amputation is considered unprotected. MTS score values and their descriptions can be found in Section 3 and the complete Doctor's Assessments can be found in Annex A.

3. Results and Discussion

The number of trials performed here was too small to compile accurate statistics but some trends were demonstrated. Whether standoff consisted of an air gap or a Styrofoam□ spacer, the greater the standoff, the less severe the injury. When the standoff consisted of an air gap, there is a clear attenuation of the injury level for standoff values of 150 mm and more; none of the surrogate legs required an amputation when standoff exceeded that value (Table 1).

Table 1. *Effect of standoff and materials on the injury level.*

STANDOFF (MM)	MATERIAL	DISPLACEMENT (MM)	ENERGY TRANSFER (J)	MTS
125	Air gap	87	27.08	2A
138	Air gap	87	26.92	2A
150	Air gap	53	16.45	1B
163	Air gap	35	10.77	1A
175	Air gap	37	11.39	1A
200	Air gap	36.7	11.42	1

However, the introduction of Styrofoam□ into the standoff space altered this result significantly, as shown in Table 2. In this case, amputation could not be avoided until the standoff distance reached 200 mm.

Table 2. *Effect of standoff and materials on the injury level.*

STANDOFF (MM)	MATERIAL	DISPLACEMENT (MM)	ENERGY TRANSFER (J)	MTS
150	Styrofoam□	75	23.28	2B
175	Styrofoam□	41	12.80	2A
200	Styrofoam□	40	12.52	1B

While only air-filled or Styrofoam□-filled standoffs were tested, it appears that the addition of mass within that space is detrimental. Further investigation, where different materials of different densities are used to fill a non-varying standoff gap, would shed light on this point and could have implications for future boot design. Based on these results, the most favourable condition seems to be an air gap.

There was a significant variation in severity of injury with standoff (see Figure 4). FSLLs were intact or only slightly damaged at standoffs of 200 mm and 175 mm while smaller standoffs (of 150 mm and 125 mm) resulted in much more significant damage. The larger standoffs also resulted in FSLLs with simple fractures that would be repairable, while the smaller standoffs resulted in significant cracking of the gelatin on the bottom of the FSLL and considerably more bone damage, including cracking and shattering. Such injuries are problematic in terms of repair.

Figure 4. Injury to FSLL with standoff of 175 mm (left) and 125 mm (right)

However, none of the standoff distances chosen resulted in any visible damage to the Combat Boot (Figure 5). This would indicate that boot damage is not necessarily an accurate predictor of lower limb injury.

Figure 5. Boot damage with standoff of 175 mm (left) and 125 mm (right)

As noted in the Materials and Methods section, the damage at 125 mm appeared severe, so intermediate standoffs of 137.5 mm and 162.5 mm (between the pre-measured distances dictated by the precut 25 mm Styrofoam□) were chosen in an attempt to delineate the effect of standoff more accurately. It was hoped that these smaller incremental increases in standoff would yield progressively less damage as standoff increased. Ultimately, we wanted to demonstrate gradations of damage with standoff so that we could identify a threshold for significant damage.

Figure 6 shows that slightly more energy was delivered to all trials conducted with foam at the same standoffs as in the air gap.

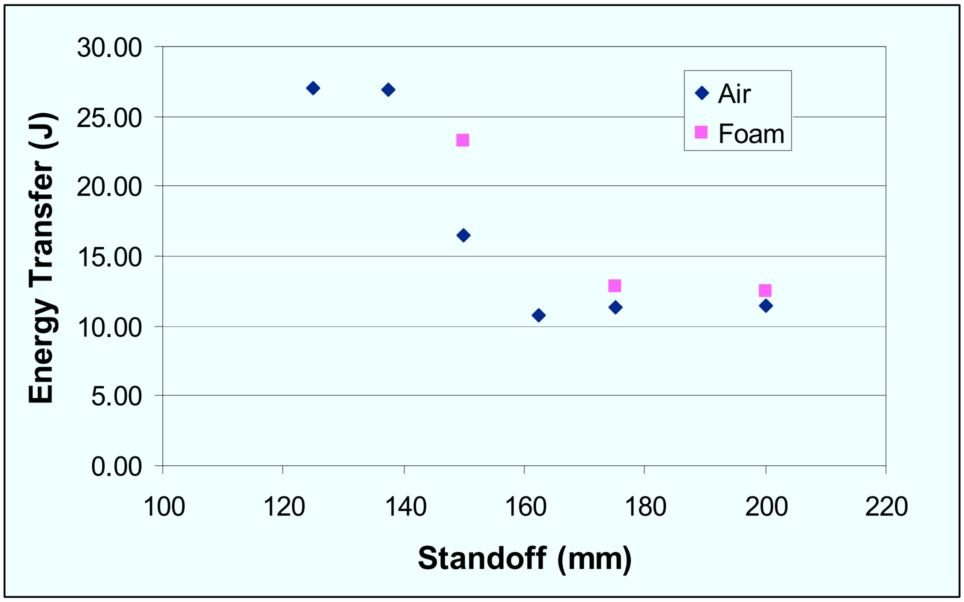

Figure 6. Energy transferred to FSLL, combat boot, and piston.

Graphs were not plotted to relate energy or standoff to injury because the MTS injury score, like other injury scores, is not linear.

The intermediate standoffs did yield information that supported the trend. It is doubtful that narrowing this range further will be helpful, given the coarse injury scores.

The trend that a greater standoff indicates greater injury reduction may be a function of the soil used. Hlady shows that standoff was effective in sand (increasing the standoff by 50% results in an average of 60% less energy transferred to the target) but that there is no difference in the prairie soil. [4] Although the data shows that with an increased standoff there is less injury, this might not be so with other soils, so standoff tests and other testing and evaluation with a variety of solids should be examined. [4]

If the degree of standoff and density of material involved turn out to be instrumental in determining injury, it would be worth exploring designs that incorporate both of these factors.

4. Conclusions

1. For all trials conducted in this experiment with dry sand, the greater the standoff the lower the energy transfer from the blast to the surrogate leg and piston rig. A different type of soil may make the standoff concept less effective or not effective at all.

2. For 75g of Composition 4 (C4) explosive, a standoff value of 150 mm and more would not have required an amputation. For Styrofoam introduced in the space, a standoff distance of 200 mm would not have required an amputation.

3. Only a limited number of trials were conducted with a limited number of conditions. More trials would be required for the experiments to be statistically sound.

4. Boot damage is not necessarily an accurate predictor of lower limb injury.

5. References

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Annex A — Mine Trauma Score

The Mine Trauma Score (MTS) was developed during the Lower Extremity Assessment Program [3] to score the injuries observed against cadaver limbs during trials to examine the effectiveness of protective footwear against AP blast mines. Each FSLL was assigned a score by the surgeon. The table below lists and describes the MTS scores.

Table 3. *Mine Trauma Score (MTS)*

SCORE	***INJURY***	***SURGERY REQUIRED***
0	Minimal	No major surgery required
1	Closed	Surgery required and limb is salvageable
1A	Open contained	
1B	Open contaminated	
2	Closed	Surgery required; definite below knee amputation
2A	Open contained	
2B	Open contaminated	
3	Open contaminated	Surgery required; could lead to either below or above knee amputation
4	Open contaminated	Surgery required; definite above knee amputation

NOTES:

Closed injury: any injury to the lower extremity that does not violate the skin, thereby minimizing the risk of infection.

Open contained injury: any injury to the lower extremity that violates the skin (lacerations, tears), but is not contaminated by the outside environment because the inner footwear was not compromised.

Open contaminated injury: any injury to the lower extremity that does violate the skin and has contamination of the soft tissues and bones from the environment where the blast occurred.

Annex B Trauma Surgeon Assessments

1. Canadian Combat Boot and FSLL damage with a 75 g C4 charge and 200 mm Standoff

Notes

Leg Serial Number: D03177A	Date: 14 July 2003
Type of Leg: FSL L; Left	Location: DRDC-Suffield
Doctor: I. Anderson	Photos: Yes
Observer: Cronin	X-Ray: No
	CT Scan: No

Damage to FSLL # D03177A

		SOFT TISSUE FOOT	CALCANEUS	PLAFONT	DISTAL TIBIA	MID, PROX TIBIA
GELATIN	***Traumatic Amputation***		No	No	No	No
	Contamination	No	No	No	No	No
	Splitting of Soft tissue		Minimal Simple Fissuring	No	No	No
	Loss of Gelatin	No	No	No	No	No
	Crushing of muscle	No	No	No	No	No
BONE	***Type of Fracture***	Lisfranc Fracture Disloc	No	Simple Closed Talus #	No	No
	Bone loss	No	No	No	No	No

Measurements

FINAL LENGTH	LEVEL OF AMPUTATION	LEG
Gelatin: 51.5 cm Bone: 51.5 cm	Gelatin: Bone:	Initial Leg Length **Saved: Yes** **Lost:**

Trauma Scale

NISSA	AIS	ICRC	MTS
Sensation: 0 Ischemia: 0 Soft tissue: 0 Skeletal: 0	1	1 F	1

Notes: Calcaneus intact with “rudder bar” type fracture of talus Plafont OK Slight fissuring of gelatin

Summary: no contamination 1 layer of surrogate skin split inner layer intact.

2. Canadian Combat Boot and FSLL damage with a 75 g C4 charge and 175 mm Standoff

Notes

Leg Serial Number: D03177B	Date: 15 July 2003
Type of Leg: FSL L; Left	Location: DRDC-Suffield
Doctor: I. Anderson	Photos: Yes
Observer: Cronin	X-Ray: No
	CT Scan: No

Damage to FSLL #D03177B

		SOFT TISSUE FOOT	CALCANEUS	PLAFONT	DISTAL TIBIA	MID, PROX TIBIA
GELATIN	***Traumatic Amputation***	No	No	No	No	No
	Contamination	No	No	No	No	No
	Splitting of Soft tissue	Slight	Slight to Plantar and Lateral Surface	No	No	No
	Loss of Gelatin	No	No	No	No	No
	Crushing of muscle	No	No	No	No	No
BONE	***Type of Fracture***	No	No	Simple Open Talus Fracture	No	No
	Bone loss	No	No	No	No	No

Measurements

FINAL LENGTH	LEVEL OF AMPUTATION	LEG
Gelatin: 51.5 cm Bone: 51.5 cm	Gelatin Bone	Initial Leg Length **Saved: Yes** **Lost:**

Trauma Scale

NISSA	AIS	ICRC	MTS
Sensation: 0 Ischemia: 0 Soft tissue: 0 Skeletal: 0	1	1 F	1A

Notes: Chaupart□s joint slightly disrupted with simple non-comminuted talar fracture possible closed (ie questionable if communicating with splitting of soft tissue)

Summary: Intact foot. No amputation.

3. Canadian Combat Boot and FSLL damage with a 75 g C4 charge and 150 mm Standoff

Notes

Leg Serial Number: D03177C	Date: 14 July 2003
Type of Leg: FSL L; Right	Location: DRDC-Suffield
Doctor: I. Anderson	Photos: Yes
Observer: Cronin	X-Ray: No
	CT Scan: No

Damage to FSLL #D03177C

		SOFT TISSUE FOOT	CALCANEUS	PLAFONT	DISTAL TIBIA	MID, PROX TIBIA
GELATIN	***Traumatic Amputation***	No	No	No	No	No
	Contamination		Moderate	Minimal	No	No
	Splitting of Soft tissue	Yes	Moderate	Moderate	No	No
	Loss of Gelatin	No	Minimal	No	No	No
	Crushing of muscle	Yes	Yes	Yes	No	No
BONE	***Type of Fracture***		Open Comminuted	Open #	No	Closed # 28 cm
	Bone loss		Possible	No		No

Measurements

FINAL LENGTH	LEVEL OF AMPUTATION	LEG
Gelatin: 51.5 cm Bone: 51.5 cm	Gelatin Bone	Initial Leg Length **Saved: Probable** **Lost:**

Trauma Scale

NISSA	AIS	ICRC	MTS
Sensation: 3 Ischemia: 2 Soft tissue: 2 Skeletal: 2	2	2FST	1B

Notes: Hard to grade. Heel split open with calcaneus fractured but little if any bone loss. Talus has a simple fracture but distal tib fib not fractured

Summary: Has undisplaced closed tib fib fracture at 28 cm from top. Probable salvageable.

4. Canadian Combat Boot and FSLL damage with a 75 g C4 charge and 125 mm Standoff

Notes

Leg Serial Number: D03177D	Date: 15 July 2003
Type of Leg: FSL L; Left	Location: DRDC-Suffield
Doctor: I. Anderson	Photos: Yes
Observer: Cronin	X-Ray: No
	CT Scan: No

Damage to FSLL #D03177D

		SOFT TISSUE FOOT	CALCANEUS	PLAFONT	DISTAL TIBIA	MID, PROX TIBIA
GELATIN	***Traumatic Amputation***	No	No	No	No	No
	Contamination	No	Mild	No	No	No
	Splitting of Soft tissue	Yes, Lisfranc	Heavy	Yes	No	No
	Loss of Gelatin	No	Moderate	No	No	No
	Crushing of muscle	Mild	Moderate	Moderate	No	No
BONE	***Type of Fracture***	Open Dislocated Lisfranc	Pulverized calcaneous	Talus intact, midfoot and chaupart disrupted, comminuted	No	No
	Bone loss	No	Yes	No	No	No

Measurements

FINAL LENGTH	LEVEL OF AMPUTATION	LEG
Gelatin: 51.5 cm Bone: 51.5 cm	Gelatin Bone	Initial Leg Length **Saved:** **Lost: BKW**

Trauma Scale

NISSA	AIS	ICRC	MTS
Sensation: 2 Ischemia: 2 Soft tissue: 2 Skeletal: 2	2	2 FST	2A

Notes: Hard to comment of contamination grit is from center part of pulverized calcaneus, Tibia intact but heel destroyed, significant injury to mid foot structures

Summary: Would need an amputation

5. Canadian Combat Boot and FSLL damage with a 75 g C4 charge and 137.5 mm Standoff

Notes

Leg Serial Number: D03177E	Date: 15 July 2003
Type of Leg: FSL L; Left	Location: DRDC-Suffield
Doctor: I. Anderson	Photos: Yes
Observer: Cronin	X-Ray: No
	CT Scan: No

Damage to FSLL #D03177E

		SOFT TISSUE FOOT	CALCANEUS	PLAFONT	DISTAL TIBIA	MID, PROX TIBIA
GELATIN	***Traumatic Amputation***	No	No	No	No	No
	Contamination	No	Mild	No	No	No
	Splitting of Soft tissue	Slight	Moderate	Heavy to Moderate at dorsum	No	No
	Loss of Gelatin	No	Yes	No	No	No
	Crushing of muscle	No	Moderate	Moderate	No	No
BONE	***Type of Fracture***	Open Lisfranc fracture	Open, Comminuted, Pulverized	Open Comminuted	No	Closed Simple 32 cm
	Bone loss	No	Yes	No	No	No

Measurements

FINAL LENGTH	LEVEL OF AMPUTATION	LEG
Gelatin: 51.5 cm Bone: 51.5 cm	Gelatin: Bone: 32 cm	Initial Leg Length **Saved:** **Lost: BKW**

Trauma Scale

NISSA	AIS	ICRC	MTS
Sensation: 2 Ischemia: 2 Soft tissue: 2 Skeletal: 2	2	2 FST	2A

Summary: Significant bone and soft tissue injury and disruption. BKW through proximal tibial fracture.

6. Canadian Combat Boot and FSLL damage with a 75 g C4 charge and 165 mm Standoff

Notes

Leg Serial Number: D03177F	Date: 15 July 2003
Type of Leg: FSL L; Left	Location: DRDC-Suffield
Doctor: I. Anderson	Photos: Yes
Observer: Cronin	X-Ray: No
	CT Scan: No

Damage to FSLL #D03177F

		SOFT TISSUE FOOT	CALCANEUS	PLAFONT	DISTAL TIBIA	MID, PROX TIBIA
GELATIN	***Traumatic Amputation***	No	No	No	No	No
	Contamination	No	Mild	No	No	No
	Splitting of Soft tissue	No	Moderate	No	No	No
	Loss of Gelatin	No	No	No	No	No
	Crushing of muscle	No	Mild	No	No	No
BONE	***Type of Fracture***	No	Open, Comminuted	No	No	No
	Bone loss	No	No	No	No	No

Measurements

FINAL LENGTH	LEVEL OF AMPUTATION	LEG
Gelatin: 51.5 cm Bone: 51.5 cm	Gelatin: Bone: 32 cm	Initial Leg Length **Saved: Yes** **Lost:**

Trauma Scale

NISSA	AIS	ICRC	MTS
Sensation: 2 Ischemia: 0 Soft tissue: 0 Skeletal: 0	1	2F	1A

Notes: Heel split with open calcaneus slightly comminuted but not pulverized. Contaminated area under calcaneous. Talus normal

Summary: Intact foot - salvageable

7. Canadian Combat Boot and FSLL damage with a 75 g C4 charge and 150 mm Standoff with Styrofoam

Notes

Leg Serial Number: D03188A	Date: 15 July 2003
Type of Leg: FSL L; Left	Location: DRDC-Suffield
Doctor: I. Anderson	Photos: Yes
Observer: Cronin	X-Ray: No
	CT Scan: No

Damage to FSLL #D03188A

		SOFT TISSUE FOOT	CALCANEUS	PLAFONT	DISTAL TIBIA	MID, PROX TIBIA
GELATIN	***Traumatic Amputation***	No	No	No	No	No
	Contamination	Minimal	Minimal	No	No	No
	Splitting of Soft tissue	Heavy	Heavy	Heavy	Minimal	No
	Loss of Gelatin	Mild	Moderate	Moderate	No	No
	Crushing of muscle	Mild	Heavy	Heavy	Mild	No
BONE	***Type of Fracture***	Open # Disloc Lisfranc	Open, Comminuted, Pulverized	Open Comminuted	No	No
	Bone loss	No	Yes	Yes	No	No

Measurements

FINAL LENGTH	LEVEL OF AMPUTATION	LEG
Gelatin: 51.5 cm Bone: 51.5 cm	Gelatin: BKW Bone: BKW	Initial Leg Length **Saved:** **Lost: BKW**

Trauma Scale

NISSA	AIS	ICRC	MTS
Sensation: 3 Ischemia: 3 Soft tissue: 3 Skeletal: 3	3	3FBK	2B

Notes: Severe injury hind and mid foot; Tibia intact
Summary: BKW

8. Canadian Combat Boot and FSLL damage with a 75 g C4 charge and 175 mm Standoff with Styrofoam

Notes

Leg Serial Number: D03188B	Date: 15 July 2003
Type of Leg: FSL L; Left	Location: DRDC-Suffield
Doctor: I. Anderson	Photos: Yes
Observer: Cronin	X-Ray: No
	CT Scan: No

Damage to FSLL #D03188B

		SOFT TISSUE FOOT	CALCANEUS	PLAFONT	DISTAL TIBIA	MID, PROX TIBIA
GELATIN	***Traumatic Amputation***	No	No	No	No	No
	Contamination	Mild	No	No	No	No
	Splitting of Soft tissue	Moderate Dorsal Forefoot	Heavy Lateral of Heel	Moderate	Mild	No
	Loss of Gelatin	No	Mild	Mild	No	No
	Crushing of muscle	Moderate	Moderate	Moderate	No	No
BONE	***Type of Fracture***	Open # Disloc Lisfranc	Pulverized	Comminuted # Talus	No	Closed Comminuted 31 cm
	Bone loss	No	Yes	No	No	No

Measurements

FINAL LENGTH	LEVEL OF AMPUTATION	LEG
Gelatin: 52 cm Bone: 52 cm	Gelatin: BKW Bone: BKW	Initial Leg Length **Saved:** **Lost: BKW**

Trauma Scale

NISSA	AIS	ICRC	MTS
Sensation: 3 Ischemia: 3 Soft tissue: 3 Skeletal: 3	3	3FBK	2A

Notes: Three level injury forefoot open and whole dorsum split. Mid and hind foot significantly damaged. Undisplaced tibial fracture

Summary: Likely a BKW. Hard to grade however

9. Canadian Combat Boot and FSLL damage with a 75 g C4 charge and 200 mm Standoff with Styrofoam□

Notes

Leg Serial Number: D03188C	Date: 15 July 2003
Type of Leg: FSL L; Left	Location: DRDC-Suffield
Doctor: I. Anderson	Photos: Yes
Observer: Cronin	X-Ray: No
	CT Scan: No

Damage to FSLL #D03188C

		SOFT TISSUE FOOT	CALCANEUS	PLAFONT	DISTAL TIBIA	MID, PROX TIBIA
GELATIN	***Traumatic Amputation***	No	No	No	No	No
	Contamination	No	No	No	No	No
	Splitting of Soft tissue	Moderate	Moderate	No	No	No
	Loss of Gelatin	No	No	No	No	No
	Crushing of muscle	No	No	No	No	No
BONE	***Type of Fracture***	# Dislocation Lisfranc	None	Open # Talus	Open # Medial Maleolus	None
	Bone loss	No	No	No	No	No

Measurements

FINAL LENGTH	LEVEL OF AMPUTATION	LEG
Gelatin: 51.5 cm Bone: 51.5 cm	Gelatin: Bone:	Initial Leg Length **Saved: Yes** **Lost:**

Trauma Scale

NISSA	AIS	ICRC	MTS
Sensation: 2 Ischemia: 1 Soft tissue: 1 Skeletal: 1	2	2FST	1B

Notes: Lisfranc and Chaupart's joints both disrupted and open Calcaneous fractured but obvious talar fracture and fracture medial maleolus

Summary: Salvageable foot

List of symbols/abbreviations/acronyms/initialisms

AIS	Abbreviated Injury Score
DRDC	Defence Research and Development Canada
FSLL	Frangible Surrogate Lower Leg
ICRC	International Committee of the Red Cross
MTS	Mine Trauma System
NISSSA	**N**erve **I**njury Ischemia **S**oft-Tissue Injury, **S**keletal Injury, **S**hock and **A**ge of Patient Score

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Combat boot covered frangible surrogate lower legs (FSLLs) were tested at different standoffs against surrogate anti-personnel (AP) mines. The standoff had air gaps and Styrofoam gaps. The effect of standoff on lower limb injury was determined by examination of the FSLLs by a trauma surgeon. Differences in energy delivered were determined using a piston apparatus. In dry sand only, the greater the standoff, the less severe the injury. Standoff with air was more effective than standoff with Styrofoam.

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