Mandible Guard Test Methodology and Injury Criteria Development

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Abstract. Military helmets must constantly evolve to improve head protection against ever changing threats encountered on the battlefield. Protection is no longer limited to projectile penetration but it also extends to the mitigation of behind armour blunt trauma, blunt impact trauma and blast effects for the whole head. The Advanced Modular Multi-threat Protective Headwear System (AMMPHS) development program was initiated by Defence R&D Canada to address these ever changing head protection requirements. Due to concerns with facial trauma stemming from ballistic strike and from blunt impact AMMPHS incorporates mandible protection. Assuming a mandible guard's ballistic requirements can be met, the issue of concern becomes the transmitted loads to the face/jaw resulting from the backface deformation of a mandible guard and blunt impact. To assess the protective performance of a mandible guard, a specification is proposed based on mandible fracture tolerance levels of post mortem human subject (PMHS) reported in published literature. Assessment of mandible trauma, however, requires a test surrogate with similar biofidelity to PMHS for ensuring similar measurements and injury assessment. With the test protocols, injury and biofidelity metrics of the PMHS established, three surrogate headforms were assessed; 1) a rigid Hybrid III headform; 2) a FOCUS headform, and; 3) a Mandible Load Sensing Headform with articulating jaw. Testing indicated that the Hybrid III and the FOCUS headforms are too stiff resulting in measured jaw loads that are much higher than that reported for PMHS under similar fore-aft and lateral impact conditions. Under the same test conditions the Mandible Load Sensing Headform produced impact loads that were also higher than the PMHS loads but, the results are more comparable than those obtained with the other headforms. Consequently, the Mandible Load Sensing Headform was recommended for the evaluation of mandible guard solutions. Mandible load tolerance thresholds were established from headform measurements obtained during impact testing similar to the PMHS tests. While further validation of the injury tolerances is required, the work represents a good foundation for defining mandible impact protection requirements

1. INTRODUCTION

Military helmets must constantly evolve to improve head protection level and coverage against ever changing threat levels from fragmentation and ballistic projectiles that can be encountered on the battlefield. Furthermore, the injury prevention afforded by a ballistic helmet is no longer limited to projectile penetration but also includes the capacity to mitigate behind armour blunt trauma (BABT), blunt impact trauma (BIT) as well as blast effects.

The Advanced Multi-threat Modular Protective Headwear System (AMMPHS) technical demonstration program, initiated by Defence R&D Canada, incorporates mandible protection as one aspect of protection a helmet is to provide to the soldier. Sources of trauma to the mandible may include direct or indirect fragmentation strike from IED’s and RPG’s, direct ballistic strike from small arms fire, and being struck by larger objects or the soldier striking fixed objects including vehicle compartments and hatches.

To assess the protective benefits that a mandible guard may have on facial injuries, an injury criterion was identified and a method by which a mandible guard can be evaluated was developed. The performance levels were established based on biomechanical tolerance levels of the mandible region that are available in the scientific literature. Three surrogate headforms were evaluated and a performance specification is recommended for assessing mandible guard based on an appropriate injury tolerance thresholds.

2. PROTECTIVE REQUIREMENTS OF A MANDIBLE GUARD

The inclusion of a mandible guard on a combat helmet will affect several helmet performance characteristic such as:

- Facial protection
- Operational stability
- Retention system securement
- Protection from fragmentation
- Low velocity impact protection
- Blast protection
- Weight
- Coverage
- Visual field of view
- Speech intelligibility
- Interface with peripheral equipment

Of interest to the current work is the protective ability of a mandible guard in regards to fragmentation and low velocity impact protection. Furthermore, the assumption is made that a mandible guard solution can be designed to meet a ballistic penetration requirement and thus the issue of concern is the resulting backface deformation loading to the face from the defeated ballistic threat or the loading from blunt impacts to the mandible.

Avoiding contact between the mandible guard and the face under all plausible ballistic and impact conditions is difficult to achieve. To do so would require a helmet suspension/retention system that provides a rigid attachment of the helmet to the head to avoid excessive shell translation or rotation. Since a perfectly rigid attachment of the shell cannot be achieved, the mandible guard would require a significant standoff from the face resulting in a larger, heavier and more cumbersome helmet. Accepting the fact that contact of the mandible guard and the mandible may occur the issue becomes that of limiting the magnitude of the forces transmitted to the face to sub-injurious level.

3. FRACTURE THRESHOLD FOR FACIAL STRUCTURES

To define an appropriate tolerance specification for the mandible guard an investigation into facial fracture tolerance levels has been carried out. Although research regarding fracture tolerance of facial structures has been conducted since the early days of automotive research, few papers have been published that document fracture tolerances of the mandible. The research that has been identified is summarized here. Of particular importance for the current effort is the tolerance data for the mandible even though other facial structures may also benefit from the impact protection afforded by a mandible guard [Figure 1]. In a military application, the extended coverage necessary to offer impact protection to the other facial structures would impinge on the field of view and therefore a clear visor would be best in providing this additional coverage.

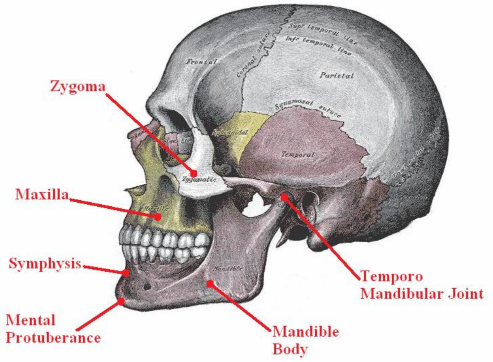

Figure 1: Facial bones that may be protected with a mandible guard [1]**.**

To establish mandible impact tolerance levels a review of mostly early automotive research that focused on the fracture of facial bones resulting from automotive accidents was undertaken. Impacts to the facial region from steering wheel rims, hubs and instrumentation panels typically guided the test conditions for the experimental studies. Their appropriateness for assessing BABT and BIT in defence applications remains to be seen, but shall be used as a basis until additional information is available. Results of tests conducted on facial regions other than the mandible are not included in the review.

Hodgson [2] investigated the impact tolerance of facial bones to blunt impact to determine the parameters affecting fracture and to aid in the safe design of vehicles. Nineteen post mortem human subjects (PMHS), ranging in age from 53 to 87 and mass from 52 kg to 108 kg, were struck on the Symphysis menti using a 6.54 cm diameter cylindrical rod with a 2.54 cm polyurethane foam covering. The line of action of the impact was through the Temporo Mandibular Joint (TMJ) with the applied force derived from an accelerometer mounted on the impactor. The average peak load for mandible fractures to occur was 2362 N.

Nahum *et al.* [3] used an impactor with a contact area of approximately 6.45 cm^2 and covered with a 5.08 mm layer of crushable nickel foam to impact the mandible of 10 PMHS ranging in age from 55 to 81 years. A load cell was incorporated into the impactor to measure the applied forces. Impacts to the mandible symphysis and mid-body were conducted where the fracture thresholds were found to range from 1557 N to 1779 N and from 1290 N to 1446 N, respectively. The results suggested that the fracture loads were insensitive to loading rate and that the fracture level for female subjects was lower than that for the males. Schneider and Nahum [4] conducted additional impact testing on 17 cadavers ranging in age and mass from 45 to 80 years and 41 kg to 121 kg, respectively, to refine the force tolerance levels for the mandible. A similar impactor to that used in the previous testing was also employed. The average peak fracture loads of the fore-aft mandible and the lateral mandible were 2845 N and 1570 N, respectively.

Hopper *et al.* [5] conducted dynamic drop tests on the mental protuberance of five, unembalmed, cadaver heads to investigate basilar skull fracture resulting from impacts to the mandible during motor vehicle accidents. The heads were disarticulated from the neck, affixed to the carriage of a drop tower, and dropped onto an impact surface with a compliance that was varied to assess the influence of the loading rate on the force response. The force of impact was measured with a load cell beneath the impact surface. An additional quasi static test was also conducted in a hydraulic test frame to test significantly lower loading rates. The average fracture tolerance of the mandible under dynamic and quasi-static loading was determined to be 5270 N. Similarly to Nahum [3], Hopper *et al.* concluded that the peak fracture load was insensitive to loading rate. However, the energy absorbed during fracture varied from 11.4 J to 119 J for rigid and compliant impact surfaces, respectively. The average mandible fracture tolerance of 5270 N found by Hopper *et al.* was much greater than the average anterior posterior fracture load of 2845 N previously published by Schneider *et al.* [4]. The difference was likely partly due to the size of the impact face 127 cm^2 compared to 6.45 cm^2 used by Schneider.

Unnewehr *at al.* [6] conducted successively increasing severity pendulum tests on seven PMHS mandibles ranging in age from 35 to 71 years. The contact area of the pendulum was not defined. The objective of the work was to investigate mandible fracture patterns and their potential forensic usefulness in determining the intensity of violent assaults. The jaw bones were removed from the head and secured in a test fixture. The impacts were applied in two different directions: fronto-median with impacts to the mental protuberance and laterally at 90° to the mandible body. The forces of impact were measured with strain gauge strips. For the fronto-median direction, the mandibles fractured at an average load of 2876 N whereas in the lateral direction the average force to fracture the mandible was 676 N. In considering these fracture loads, it must be remembered that the mandible experienced several impacts prior to the resulting fracture. Although low-level control impacts were performed before each test to verify the integrity of the mandibles, the dependability of the measured fracture levels is questionable.

Viano *et al.* [7] conducted blunt ballistic impact tests to the mandible of six cadavers to establish corridors for high-speed low mass impacts that are representative of the kinetic energy of less than lethal weapon projectiles. The projectiles were 37 mm in diameter with a flat rigid impact face and a mass ranging from 25 g to 35 g. The speed at impact was 42±10 m/s. The impacts were centered on the mental protuberance and the impact forces were determined from an accelerometer mounted in the projectile. There were no observed fractures of the mandible at force levels of 3.0±1.0 kN. In comparing their results to other published low-speed fracture data, Viano *et al.* concluded that the fracture of the mandible is not sensitive to loading rate. Based on their analysis, a fracture tolerance level of 1.9 kN was suggested.

Viano *et al*. also determined that a contact area of 13 cm^2 as a threshold between concentrated loading and distributed loading, albeit it was in relation to compressed fractures of the cranium. It was also suggested that as the contact area decreases below 5 cm^2, a depressed skull fracture may transition into a punch-through failure the size of the projectile. Therefore the area of loading must be considered in establishing loading tolerances for the mandible, which is corroborated by Hopper *et al.*'s findings [[5]].

A summary of the mandible fracture loads identified by the various researchers is presented in Table 1 and Table 2.

Table 1: Fore-aft mandible fracture loads.

Mandible: Symphysis/Mental Protuberance (fore-aft)			
Impactor Description	**Fracture Loads (N)**		**Reference**
	Range	**Average**	
- flat, circular, 33.55 cm^2 - 25.4 mm polyurethane padding	1601 to 2669	2362	Hodgson [2]
- flat, circular, 6.45 cm^2 - 5.08 mm crushable nickel foam face	1557 to 1779	n/a	Nahum *et al.* [3]
- flat, circular, 6.45 cm^2 - 2.54 mm crushable nickel foam face	1890 to 4120	2845	Schneider and Nahum [4]
- flat, circular, 127 cm^2 - various compliant surfaces on anvil	4460 to 6740	5270	Hopper *et al.* [5]
- flat, circular, unspecified impactor - contact are not defined	2465 to 3122	2876	Unnewehr *et al.* [6]
- flat, circular, 10.8 cm^2 - rigid	n/a	4301	Viano *et al.* [7]

Table 2: Lateral mandible fracture loads.

Mandible: Mid-Body (Lateral)			
Impactor Description	**Fracture Loads (N)**		**Reference**
	Range	**Average**	
- flat, circular, 6.45 cm^2 - 5.08 mm crushable nickel foam face	1290 to 1446	n/a	Nahum *et al.* [3]
- flat, rectangular, 25.4 mm x 101.6 mm - 5.08 mm crushable nickel foam face	820 to 2600	1570	Schneider and Nahum [4]
- flat, circular, unspecified impactor - contact are not defined	633 to 763	676	Unnewehr *et al.* [6]

The wide variation in load tolerance observed in the published literature is likely due to differences in the specimens and/or test protocols. As indicated above, the studies showed a dependency between the fracture threshold and contact area of the impactor where an impact resulting in a loading area of 13 cm^2 was identified as a threshold between distributed and concentrated loading regimes.

The loads presented in Table 1 and Table 2 relate to direct impacts to the mandible. In assessing the performance of a mandible guard, the impact load would be transmitted through the mandible guard which will influence the contact characteristics with the jaw. For the purposes of establishing a criteria for assessing the mandible guards of military helmets, the loads resulting from the back face deformation caused by a non-penetrating ballistic strike were considered to be a concentrated load whereas the loading caused by a blunt impact were considered to be in the distributed loading regime.

Fracture loads for the mandible were defined for each of these regimes and whether the impact is to the mandible body or the mental protuberance. The ranges of loads that apply to these loading regimes are summarized in Table 3.

Table 3: Range of fracture loads measured in the PMHS testing.

Loading Direction		**PMHS range of Results (N)**
Fore-aft (Impact to the mental protuberance)	Focal	1557 - 4120
	Distributed	1601 - 6740
Lateral (Impacts to the mandible body)	Focal	1290 - 1446
	Distributed	820 - 2600

4. SURROGATE HEADFORMS FOR ASSESSING MANDIBLE GUARD IMPACT PERFORMANCE

Three dummy headforms, with the capability to measure transmitted forces to the chin, were identified as potential surrogates for assessing the performance of a mandible guard. They were:

1. Hybrid III 50th percentile male head with an instrumented rigid chin (Denton ATD Inc., Rochester Hills, Michigan)
2. Facial and Ocular CountermeasUre Safety (FOCUS) headform (Denton ATD Inc., Rochester Hills, Michigan)
3. Articulating Mandible headform (Biokinetics and Associates Ltd., Ottawa, Ontario).

4.1 Hybrid III Headform with an Instrumented Chin

A standard Hybrid III headform was modified[1] by cutting off the chin and re-attaching it via a three axis load cell to study the load paths to the cranium through helmet retention systems and face guards of American football helmets. Compliance of the structure is obtained strictly from the standard Hybrid III head skin. The head is shown in Figure 2.

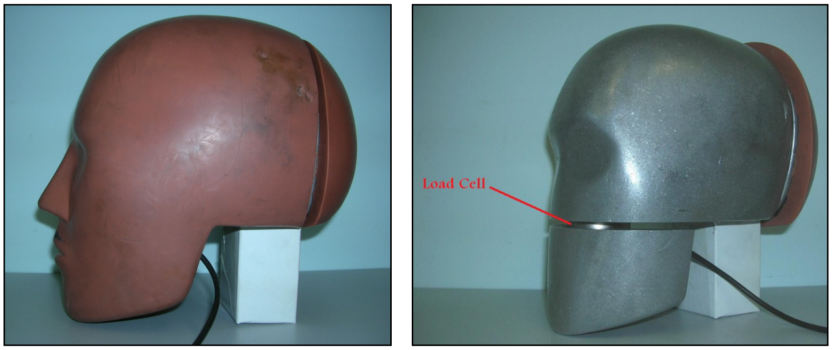

Figure 2: Hybrid III with an instrumented chin

4.2 FOCUS Headform

The FOCUS headform is a rigid mechanical headform that has been designed to test and evaluate head protective devices under impact conditions. In addition to being able to measure the forces on the eye, sensors installed in the head allow for the measurement of forces acting on the frontal, maxilla, zygoma, mandible and nasal bones. Skin thickness is varied to provide appropriate biofidelity in the different facial regions. The FOCUS headform is shown in Figure 3.

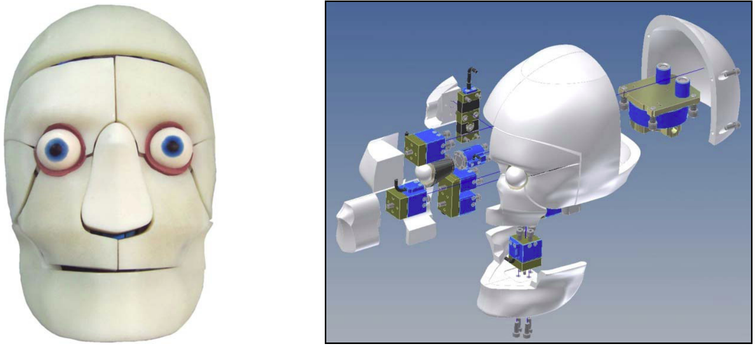

Figure 3: Focus headform without head skin (photos from Denton ATD Inc. [8]).

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[1] Modifications to the Hybrid III headform were made by Denton ATD. A modified Hybrid III headform with a rigid load sensing jaw is available from Denton ATD.

4.3 Articulating Mandible Headform

The articulating mandible headform was developed for the National Football League and is intended for the dynamic assessment of mouth guards in the football environment as they relate to brain injury. The headform is based on the Hybrid III crash test dummy head with an articulating and force-sensing mandible and mechanical teeth[2]. Its biofidelity to sub-fracture loading levels has been verified in a series of chin impact experiments with post mortem human subjects [9]. The headform is shown in Figure 4.

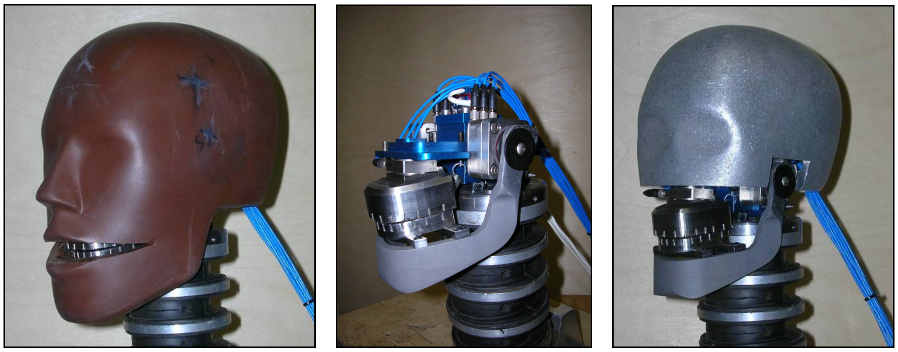

Figure 4: Articulating mandible headform.

5. TESTING TO EVALUATE THE BIOFIDELITY OF SURROGATE HEADFORMS

The test methodology used by Nahum *et al.* [3] and by Schneider and Nahum [4] is well documented and was therefore used to assess the performance and biofidelity of the surrogate headforms to focal loading on the mental protuberance (front of the chin) and distributed loading on the mandible body (lower part of the jaw). The parameters of each test configuration are summarized in Table 4.

Table 4: Test set-up for focal and distributed loading evaluations of surrogate headforms.

Test Parameter	Focal Loading	Distributed Loading
Impact Location	mental protuberance	mandible body
Impact Direction	inline - mandible condyle	normal to mandible body
Impactor Contact Area	6.45 cm^2	2.54 cm x 10.2 cm
Contact Geometry	circular	rectangular
Impactor Material	Steel	Steel
Contact Surface of Impactor	2.00 mm nickel foam (see note) 95% porosity 500 g/m^2 40 ppcm pore size	4.00 m nickel foam (see note) 95% porosity 500 g/m^2 40 ppcm pore size
Drop Mass	3.12 kg	3.81 kg
Impact Velocity	5.46 m/s	5.73 m/s
Head Support	soft polyurethane foam wedges	
Note: In Schneider and Nahum [4] ,the nickel foam was 2.54 mm and 5.08 mm thick for the focal and distributed loading tests, respectively. However, only 2.00 mm nickel foam was available. One layer was used for the focal loading tests and two layers for the distributed loading tests.		

For impacts to the chin, a headform without a neck was supported by foam wedges on a heavy pedestal and positioned/supported as per Schneider and Nahum's test setup. For impacts to the mandible body, the headform was installed on a Hybrid III neck mounted to a rigid lower neck bracket which was bolted to the test pedestal. In both configurations, the headform's positioning was achieved using three targeting lasers fixed to the laboratory reference. The lasers ensured repeatable positioning of three targets affixed to the headform. The two different test configurations are shown in Figure 5.

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[2] The articulating mandible headforms is produced by Biokinetics and Associates Limited.

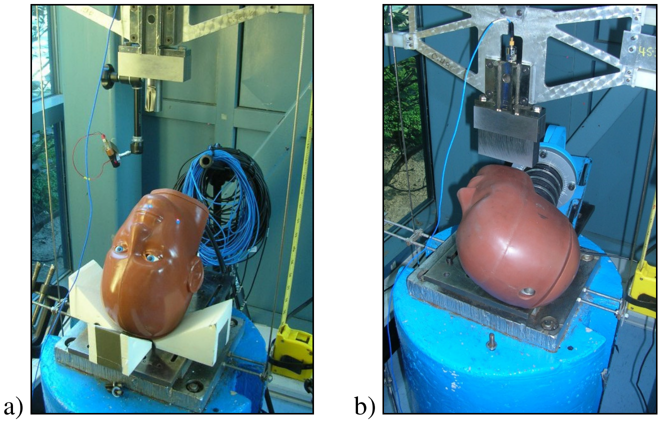

Figure 5: a) Focal loading set-up, b) Distributed loading test set-up.

An accelerometer mounted to the impactor was used to calculate the impact force which could be correlated back to the PMHS data. Data from the headform's load cells and the impactor accelerometer were recorded with a sampling frequency of 10 kHz following standard SAE J211 practices. The acceleration data were filtered with CFC 1000 filters whereas the headform's load cell data was filtered using CFC 600 filters. All the testing was conducted under ambient environmental conditions (21 ± 2 °C).

The total force acting on the jaw of the articulated mandible headform was calculated from its three triaxial load cells which measure the reaction loads in the forward, lateral and vertical directions at each of the TMJs and the upper dentition. The resultant load is calculated by first summing the load in each of the three orthogonal directions from the three different load cells and then calculating the resultant load.

The impact velocity was increased from a low impact severity up to the impact velocity used by Schneider and Nahum [4]. The headforms were impacted three times at each velocity. The average result for each impact velocity is presented in Table 5.

Table 5: Summary of impact test results (average of three impacts).

Impact Description	**Impact Velocity (m/s)**	**Hybrid III with Instrumented Chin**		**FOCUS Headform**		**Articulating Mandible Headform**	
		Measured Jaw Force (N)	**Impactor Force (N)**	**Measured Jaw Force (N)**	**Impactor Force (N)**	**Measured Jaw Force (N)**	**Impactor Force (N)**
Focal Impacts to the Chin	1.50	756	955	1141	1150	608	943
	3.00	2059	2490	2614	2502	1495	2121
	4.50	4410	4946	5741 (2)	5370 (2)	2824	3720
	5.46(1)	7787 (2)	9932 (2)	No Data (3)	No Data (3)	3916	4776
Distributed Impacts to Mandible Body	1.50	909	1094	No Data (3)	No Data (3)	315	529
	3.00	1987	2501	No Data (3)	No Data (3)	942	1315
	4.50	4030	5133	No Data (3)	No Data (3)	1503	2841
	5.73(1)	6068	8116	No Data (3)	No Data (3)	2436	5026

Notes:
(1) Impact velocities used in the Schneider and Nahum PMHS testing.
(2) Single impact. Testing terminated due to concern over damaging the test equipment.
(3) Single impact. Testing was terminated because the peak loads were approaching the capacity of the FOCUS headform's load cells.

Correct headform biofidelity is required to ensure proper impact biomechanics and correlation of the headform response in relation to the injury parameter being measured. The compliance of both the Hybrid III headform with the instrumented chin and the FOCUS headform is achieved strictly through the vinyl skin covering the headforms, resulting in structures that are stiffer than the PMHS. Consequently the impactor loads are much higher than the range of loads recorded for the PMHS results shown in Table 3.

Similarly, the impactor loads upon striking the articulating mandible headform were also found to be higher than the PMHS results. The average impactor load in the fore-aft focal loading configuration was approximately 16% higher than the range reported for the PMHS testing, whereas, in the lateral direction the average impactor loads measured during the distributed loading configuration were approximately 93%

higher. These loads are likely higher for the articulating mandible headform because the mild steel construction of the mandible does not deform/fracture and absorb energy as would bone, even though the force displacement of the jaw has been found to be biofidelic at lower energy inputs [8]. Although fabricated from a rigid element, the mandible has the capacity to displace due to the compliance of the TMJ which provides additional ride-down distance resulting in improved performance over the rigid jaws of the Hybrid III and FOCUS headform designs. During similar testing, the rigid Hybrid III headform loads were approximately 141% and 212% higher for the focal and distributed loadings respectively. Furthermore, testing on the rigid FOCUS headform could not be completed because the measured loads in the headform were approaching the rated capacity of the transducers installed in the headform.

Measuring applied load with an accelerometer on the impactor is a convenient and easily implemented method for use in controlled laboratory testing when assessing the performance of the headforms. However, for practical purposes, this method is not possible for the likely testing configurations of a mandible guard solution where, for example, the impact may be the result of a non-penetrating ballistic strike. What is important is the load transmitted to the jaw behind the mandible guard and not necessarily the applied load to the mandible guard.

Accepting the fact that the articulating mandible headform is more rigid than a human mandible at the energy levels required to cause fracture, it remains the best of the three headforms that were evaluated for assessing behind armour loading to the mandible.

6. PROPOSED INJURY TOLERANCE LEVEL FOR THE ARTICULATING MANDIBLE HEADFORM

It is proposed that, given that the impact energies to the mandible headform were the same as those in the PMHS tests, the average computed load cell response of the mandible headform can be correlated directly to the average fracture threshold identified in the PMHS testing. These average loads are summarized in Table 6 which includes the ranges of loads measured.

Table 6: Summary of PMHS and mandible loads.

Load Direction	PMHS Results Average Load (N) (Load Range)	Articulating Mandible Headform Average Load (N) (Load Range)
Fore-aft (focal)	2845 (1557 - 4120)	3916 (3839 - 4057)
Lateral (distributed)	1570 (820 - 2600)	2436 (2209 - 2748)
Note The mandible headform loads are derived from the TMJ and upper dentition loads.		

Based on the measured response of the articulating mandible headform compared to the PMHS data, a preliminary performance specification is proposed for the fore-aft and lateral impact directions for both focal and distributed loading scenarios. These proposed performance specifications are presented in Table 7 where, the thresholds indicated represent mandible fracture tolerance levels.

Table 7: Proposed articulating mandible headform performance thresholds representing mandible fracture.

Loading	Articulating Mandible Headform	
	Fore-aft	Lateral
Focal	< 3916 N	< 2436 N (see note)
Distributed	< 3916 N (see note)	< 2436 N
Note: Although the indicated tests were not conducted due to insufficient published data needed to replicate the testing, it is expected that the response of the headform would be similar whether a small area impactor or large area impactor were used because of the rigidity of the jaw element of the articulating mandible headform.		

Using the fracture thresholds, the effectiveness of a mandible guard concept can be evaluated for both blunt impacts and from more localized loading such as from a non penetration ballistic strike. It should be noted that less severe injuries, such as broken teeth, may occur at levels below these suggested fracture tolerance levels but no data is available.

7. LIMITATIONS

The articulating mandible headform was originally designed for assessing the performance of mouth guards at sub fracture impact energy levels associated with North American football impacts. Therefore, it is understood that the extended use of the headform for assessing fracture is not ideal because of its rigid components which do not fracture as would bone, resulting in higher measured loads when compared to available cadaver data. Regardless of the current limitations, the headform remains the best available tool for evaluating the relative performance of AMMPHS mandible guard designs. Ideally, the mandible component of the headform would be constructed out of a bone simulant having the same fracture response as bone; however, this is beyond the scope of the current AMMPHS program.

The proposed injury criteria, which is based on limited test data, simply provides a first cut at establishing an acceptable protective level against which AMMPHS designs can be compared. It is understood that additional cadaver testing under more representative battlefield loading conditions are required to better define an appropriate injury criteria and that the test need to be replicated with the mandible headform. As with the mandible material, there is neither funding nor plans to conduct further cadaver testing to better define an injury criteria.

8. SUMMARY

Incorporating mandible protection in the design of a combat helmet necessitates a test surrogate for assessing the performance of a mandible guard concept. Three headforms were evaluated for this purpose: the Hybrid III headform with an instrumented jaw, a FOCUS headform and an articulating mandible headform. The Hybrid III and the FOCUS have a rigid jaw whereas the mandible headform incorporates an articulating and compliant jaw component.

As a means of establishing acceptable loading thresholds, published research into the fracture tolerance of the mandible was reviewed. The studies have shown dependency between the fracture threshold and contact area of the impactor. An impact resulting in a loading area of 13 cm^2 was identified as a threshold between distributed and concentrated loading regimes. The loads resulting from the back face deformation caused by a non-penetrating ballistic strike could be considered as a concentrated load whereas the loading caused by a blunt impact could be considered in the distributed loading regime.

In comparing the response of the three surrogate headforms to fracture data from PMHS trials in which the load required to cause fracture was measured, the articulating mandible headform performed the best. Additional published comparison of the articulating mandible headform's force deflection characteristics to those of available PMHS has shown the headform to be biofidelic at low energy impacts that do not result in fracture. However, at impact levels required to cause fracture in the PMHS, the measured force on the impactor was found to be higher. These higher forces are likely due to the rigid steel construction of the mandible component which does not fracture and absorbs energy as would bone.

To improve the mandible headform's response would require a compliant mandible element with stiffness characteristics similar to those of a human mandible. This would require additional research to be conducted into the force displacement characteristics of the human mandible up to the point of fracture. Until such research data becomes available, it is proposed that the computed response from the headform's load cells can be correlated directly to the average injury threshold identified in the review of the PMHS data.

Fracture tolerance levels based on the mandible headform's response when impact tested using the same methodology as that used in PMHS testing were established to be 3916 N and 2436 N for the fore-aft and lateral directions respectively. Until additional data becomes available from which fracture probability curves can be developed, it is proposed that measured loads in excess of these values correspond to mandible fracture.

With the articulating mandible headform selected as the most appropriate headform for assessing mandible guard performance and an injury tolerance level defined, further testing to evaluate the proposed test methodology with a helmet/mandible guard installed is required.

Acknowledgements

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