# EXPERIMENTAL EVALUATION OF HUMAN FACIAL TOLERANCE TO INJURIES

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ABSTRACT

Facial injuries remain an important problem for restrained drivers involved in frontal accidents. This paper analyses the data available from impact biomechanics literature dealing with human tolerance to facial injuries, compares the results of a new series of cadaver facial tests with the proposed limits for the tolerance, and proposes tolerance values for other facial impact locations.
The last part deals with the methods for facial injury protection assessment.

## MECHANISMS OF FACIAL INJURIES

The use of restrain systems has greatly improved the protection of car occupants especially in frontal impact. However a safety belt leaves some freedom to the restrained occupant in terms of kinematic: some body segment may move during the crash from their original position, and this is especially true for the head. for the best occupant protection no body segment may hit any component of the passenger compartment. This is difficult to ensure to the driver who has the steering wheel close to him, and which may move rearward and upward during the impact. It has to be noted that a present regulation limits the steering wheel motion horizontally but not vertically.
This makes understandable that facial injuries may occur in frontal impact accidents and may concern primely the driver.
Analysis of 217 frontal impacts all with restrained frontal occupants showed that more than 30% of the drivers sustained head injuries, and most of them facial injuries as indicated in table 1 (1). The steering wheel was considered as the source of such injuries in more than 40% of cases.

| Local Region | Percent with injury |
|---|---|
| Skull Soft Part | 7.4 |
| Skull Fracture | 4.6 |
| Cerebral Injury | 10.6 |
| Face Soft Part | 23.0 |
| Eyes Injury | 6.5 |
| Facial Fracture | 5.1 |

Table 1 : Frequency of Injury to the head for 217 restrained drivers involved in a frontal collision (1).

Another analysis based on a larger number of cases (2) showed that more than 20% of restrained drivers sustained facial injuries related to steering wheel contact, and that the steering wheel is contacted by the driver's head in more than 60% of cases for 50/59 km/h delta V frontal accidents.

## AVAILABLE BIOMECHANICAL DATA

Within the studies published in the literature dealing with impact biomechanics, three are of great interest as they take into account the injury mechanisms of facial injuries to the restrained driver.

NYQUIST (3) published the results of 11 cadaver facial impacts. In these tests the cadaver is hit in the nose area by a 25mm diameter attached to the extremity of an impactor. The impact force as well as the facial deflexion were recorded. All the cadavers sustained facial injuries, and for 7 out of the 11 cases these injuries were nasal bone fractures; the four remaining sustained more extensive facial fractures. Results of these tests show that nasal fractures can occur at a kinetic energy as low as 241 J. It may need a lower energy to produce such injuries, as all the cadavers sustained a nasal fracture, and then it is not possible to determine precisely a tolerance limit.

A new analysis of the tests in which the cadaver sustained only nasal fracture (4) allowed to define the corridor shown on fig 1 for 2.8 to 4.8 m/s impact tests.

In the same paper is reported the result of 5 cadaver facial impact tests in which a 13Kg impactor hits the cadaver face in the nasal area. Fig 2 show the proposed force/time corridor for 6.7 m/s impact tests.

## COMPLEMENTARY BIOMECHANICAL DATA

INRETS in cooperation with TRANSPORT CANADA (5) has performed facial impacts on 8 cadavers to complete the available biomechanical data base and to verify the proposed tolerance values.
Most cadavers sustained four impacts in the following sites:

-chin 45° upward

-chin horizontal (if no injury after the 45° impact)

-sub nasal maxillary horizontal

-nasion horizontal

A total of 29 impactor tests using 8 cadavers were performed.
In these tests the cadaver is in a seating posture, and is hit on its face by an horizontal steel bar (simulating a steering wheel) attached to the mobile part of an impactor. The weight of the impacting mass is 16.6 kg, and it is guided horizontally.
Table 2 summarizes the results of these tests.

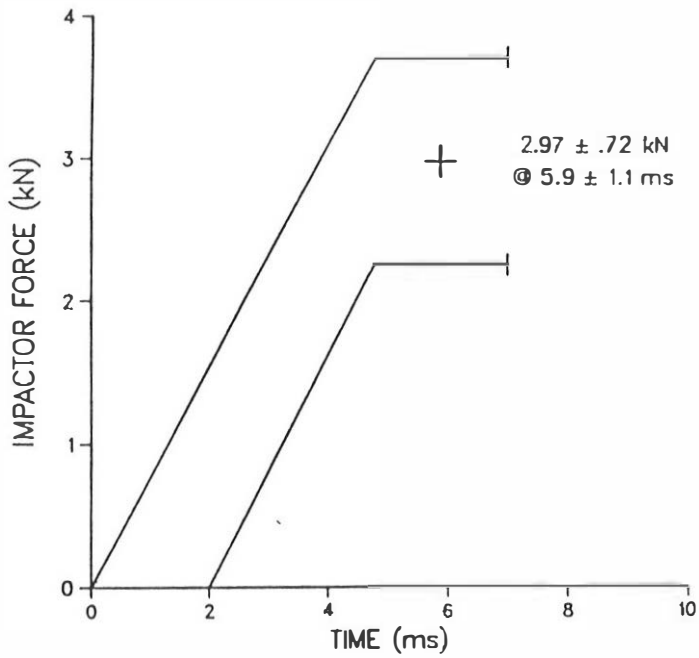



Fig 1. Proposed Tolerance Corridor for 2.8/4.8m/s impact test (3)

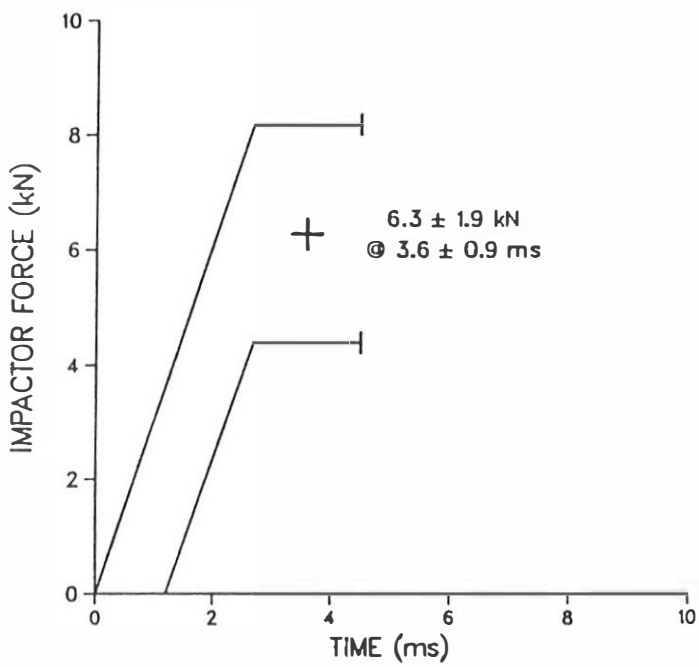



Fig 2. Proposed Tolerance Corridor for 6.7 m/s impact Test (3)

| Impact type | Cadaver | Test# (Sex, Age) | Impact speed (m/s) |
|---|---|---|---|
| Cin 45° | F84 | CFC02 | 1.31 |
| Chin 0° | | CFC03 | 1.40 |
| Maxillary | | CFC04 | 1.40 |
| Nasion | | CFC05 | 3.25 |
| Chin45° | M64 | CFC06 | 1.82 |
| Chin 0° | | CFC07 | 1.85 |
| Maxillary | | CFC08 | 1.35 |
| Nasion | | CFC09 | 3.08 |
| Chin 45° | M66 | CFC10 | 1.86 |
| Chin 0° | | CFC11 | 1.94 |
| Maxillary | | CFC12 | 1.98 |
| Nasion | | CFC13 | 3.86 |
| Chin 45° | M75 | CFC14 | 2.67 |
| Chin 0° | | CFC15 | 2.67 |
| Maxillary | | CFC16 | 3.14 |
| Nasion | | CFC17 | 3.03 |
| Chin 45° | M69 | CFC20 | 3.03 |
| Chin 0° | | CFC21 | 3.11 |
| Maxillary | | CFC22 | 1.95 |
| Nasion | | CFC23 | 3.67 |
| Chin 45° | M72 | CFC25 | 3.03 |
| Chin 0° | | CFC26 | 3.06 |
| Maxillary | | CFC27 | 2.30 |
| Nasion | | CFC28 | 3.67 |
| Maxillary | M82 | CFC30 | 3.19 |
| Nasion | | CFC31 | 2.27 |
| Maxillary | F17 | CFC32 | 3.22 |
| Nasion | | CFC33 | 2.26 |
| Chin 0° | | CFC34 | 2.24 |

Table 2 : Impact conditions of cadaver facial tests

Tolerance of the Nasion

The results of the 8 nasion impacts are indicated in table 4

Six tests were performed in the speed range 2.8 to 4.8 m/s for which there is a proposed tolerance corridor. The two other tests were conducted at a lower speed around 2.3 m/s impact speed: the first one sustained a nasal bone fracture, and the second one a microfracture of the frontal bone, both corresponding to a force time history partly below the lower limit of the proposed corridor. The other tests results are within the proposed corridor, except test 28 for which the force peak occurs later and test 23 which gives a maximum force higher than the upper limit, but with an involvement of the frontal bones. It has to be noted that in two cases there was no nasal bone fracture, even if the force time history was

within the proposed corridor. The reached point was at the top of the nose, but as this point is close to the skull, there is a possibility that the frontal bone is also involved by the impact.

| Test# | Impact speed (m/s) | Impactor kinetic energy (J) | Maximum force (N) | Injuries |
|---|---|---|---|---|
| CFC05 | 3.25 | 87.5 | 2503 | Fracture of nasal bones and septum |
| CFC09 | 3.08 | 78.6 | 2918 | No fracture |
| CFC13 | 3.86 | 123.4 | 2781 | Le Fort TYPE III fracture |
| CFC17 | 3.03 | 76.1 | 3403 | No fracture ; impact to frontal bone above nasion |
| CFC23 | 3.67 | 111.6 | 3760 | Fracture ar junction of nasal and frontal bones |
| CFC28 | 3.67 | 111.6 | 2225 | Le Fort TYPE III fracture |
| CFC31 | 2.27 | 44.7 | 1875 | Fracture of nasal bones |
| CFC33 | 2.26 | 44.2 | 1789 | Microfracture at junction of nasal and frontal bones |

Table 3 : Nasion Impact Tests Results

Tolerance of the Maxillary

All the cadavers sustained a maxillary impact, and the results of these tests a listed in table 5
Five cadavers sustained a fracture of the nasal spine whereas the three other did not show any injury. Two tests have to be considered with caution: test #CFC04 made with the oldest female cadaver, which got nasal spine fracture at a low impact force value, and test #CFC32 made with a very young cadaver, and then probably more resistant than the population at risk. If we exclude these two tests, the cadaver was uninjured for an impact force up to 670N, a partial fracture was found at 790N impact force, and the complete fracture occurs for an impact force above 1150N. This indicates that the facial tolerance is lower

when the impact occurs on the maxillary just below the nose, than in the cases where the nose is directly hit.

| Test# | speed (m/s) | Kinetic energy (J) | force (N) | |
|---|---|---|---|---|
| CFC04 | 1.40 | 16.2 | 516 | Fracture of nasal spine |
| CFC08 | 1.35 | 15.1 | 660 | No fracture |
| CFC12 | 1.98 | 32.5 | 673 | No fracture |
| CFC16 | 3.14 | 81.7 | 1254 | Fracture of nasal spine |
| CFC22 | 1.95 | 31.5 | 788 | Partial fracture of nasal spine |
| CFC27 | 2.30 | 43.8 | 1148 | Fracture of nasal spine |
| CFC30 | 3.19 | 88.2 | 1361 | Fracture of nasal spine |
| CFC32 | 3.22 | 89.9 | 1049 | No fracture |

Table 4 : Sub Nasal Maxilla Impact Tests Results

Tolerance of the Mandible.

Seven cadavers sustained impacts to the chin, and all except one two consecutive impacts: the first one with an angle of 45° from the horizontal, and the second in the horizontal direction. Table 6 contains the results of these tests.
Apparently none 45° impacts produced injuries, and three cadavers showed injuries after the second impact, the four other being uninjured. Analysis of the three injury producing tests it has to be remarked that soft tissue injuries occured for an impact force just above 650N in the two cases, and a fracture of a condyle was found with an impact force close to 680N, but the small number of tests with bone injuries does not allow to conclude in terms of human tolerance to mandible impacts.

| Test# | Angle | Impact speed (m/s) | Impactor Kinetic Energy (j) | Maximum Force (N) | Injuries |
|---|---|---|---|---|---|
| CFC02 | 45° | 1.31 | 14.2 | 315 | |
| CFC03 | 0° | 1.14 | 16.3 | 387 | No Injury |
| CFC06 | 45° | 1.82 | 27.5 | 520 | |
| CFC07 | 0° | 1.85 | 28.4 | 352 | No Injury |
| CFC10 | 45° | 1.86 | 28.7 | 542 | |
| CFC11 | 0° | 1.94 | 32.2 | 525 | No Injury |
| CFC14 | 45° | 2.67 | 59.2 | 604 | |
| CFC15 | 0° | 2.67 | 59.2 | 663 | Cutaneous erosion |
| CFC20 | 45° | 3.03 | 76.2 | 1860 | |
| CFC21 | 0° | 3.11 | 80.3 | 683 | Wound and Mandible Condyle Fracture |
| CFC25 | 45° | 3.03 | 76.2 | 969 | |
| CFC26 | 0° | 3.06 | 77.7 | 654 | Wound No fracture |
| CFC34 | 0° | 2.24 | 43.6 | 426 | No Injury |

Table 5 : Mandible Impact tests results

## METHODS FOR FACIAL PROTECTION ASSESSMENT

The HIC which is commonly used for head protection evaluation is not able to predict the risk of facial injury, and there was several attempts to design devices to be fitted on dummy head to predict the risk of facial injury. Peugeot Renault Association has proposed to place an aluminium honeycomb shaped block between the facial skin and a flat surface on the PART 572 (Hybrid II) head (6). The research showed that this device gives the same force deflexion than a cadaver submitted to a facial impact. However the impact force seems high compared to currently proposed tolerance limit. This face has a uniform force deflexion characteristic which differs from the human face, and the interpretation was based on the deformed volume of honeycomb. This head was covered with a polyurethan skin capable to predict soft tissue injuries.

Biokinetics has proposed to modify hybrid III head by adding a frangible face piece (7). Evaluation of the response to impacts of such modified Hybrid III head showed a good biofidelity; however the device has a yes/no response.

Volvo has proposed to measure the impact force by fitting a modified Hybrid III face with a matrix of small piezo-electric pressure transducer (8), and the evaluation on such device in steering wheel impacts was recently made. This device has the advantage to give the distribution of the force on the face.

Recently Melvin(4) has developed a contact force measurement method and proposed modifications to Hybrid III head to include a replaceable deformable face. Evaluation of the response of this face using the

contact force measurement technique in distributed load and in steering wheel impacts showed a good biofidelity.

## DISCUSSION AND CONCLUSION

To improve the protection of the restrained driver in frontal impact accidents several researches dealing with facial injury mechanisms tolerance and protection assessment methods were recently performed. These researches confirm the low tolerance of human facial bones to impacts, and a variation in terms of tolerance and of force/deflexion characteristics according to the location and the direction of the impact. Three main methods for assessing the facial protection are proposed: the first one consists of a frangible facial insert, which may gives an impact response similar to the human one; as it has a yes/no response it does not allow to know neither how far is a specific test response from the proposed limits nor at which time the fracture occurs. The second one consists in the measurement of the distribution of the pressure on the face; it allows to know the force applied to a specific facial area, however it is a relatively complex and expensive measurement system. The third one is

## REFERENCE


1. D. OTTE, N. SUDKAMP, H. APPEL. "Residual Injuries to Restrained Car-Occupants in Front and Rear-Seat Positions"
11th ESV Conference, Washington D.C., May 1987

2. G. WALFISCH, D.POUGET, C. THOMAS, C. TARRIERE. "Head Risks in Frontal Impacts : Similarities and Differences Between Tests And Real-Life Situations"
12th ESV Conference, Gothenburg SWEDEN, May 1989

3. G.W.NYQUIST, J.M. CAVANAUGH, S.J. GOLDBERG, A.I. KING. "Facial Impact Tolerance and Response"
30th STAPP Car Crash Conference, pp. 379-400, SAE 1986.

4. J.W MELVIN, T.R. SHEE. "Facial Injury Assessment Techniques"
12th ESV Conference, Gothenburg SWEDEN, May 1989.

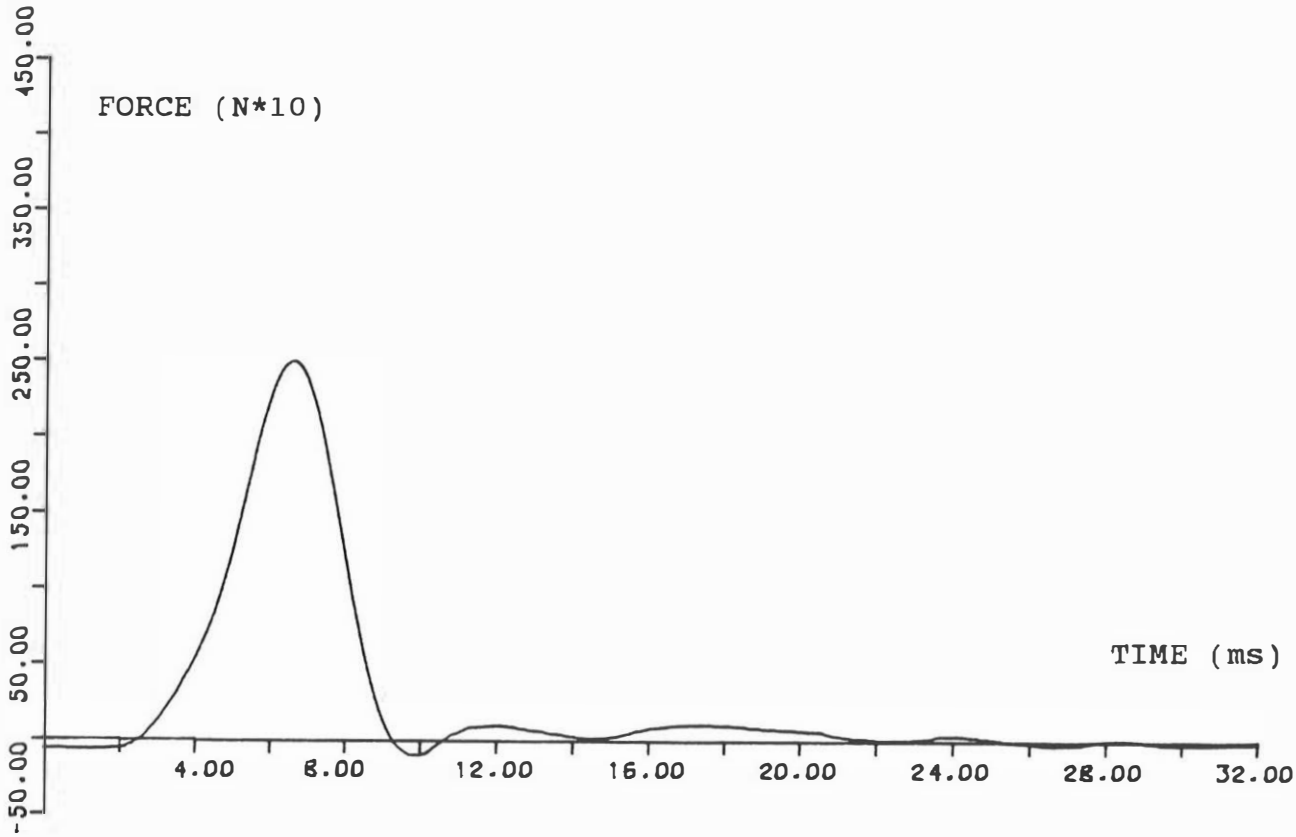
5. E. WELBOURNE, M. RAMET, M. ZAEREBSKI. "A comparison of Human Facial Fracture Tolerance with the Performance of a Surrogate test Device"
12th ESV Conference, Gothenburg SWEDEN, May 1989.

6. C.TARRIERE, Y;C.LEUNG, A.FAYON, C.GOT, A. PATEL, P. BANZET. "Field Facial Injuries and Study of their Simulation with Dummy.
25th STAPP Car Crash Conference, pp435-468 SAE 1981.

7. J.A. NEWMAN, B;M. GALLUP. " Biofidelity Improvements to the Hybrid III Headform"
28th STAPP Car Crash Conference,pp. 87-99 SAE 1984.

8. I. PLANATH, S. NILSSON, D. CESARI "Facial Fracture for the Hybrid III Load Sensing Face"
To be presented at the 33rd Annual meeting of the Association for the advancement of Automotive Medicine. Baltimore, MD October 1989.

## APPENDIX




Test CFC 05 - Force/time history.