potential injury from the steering system of a vehicle.

To enable this, data has been obtained from pendulum impact tests on steering wheels and a satisfactory representation created on a simple, pre-processor CVS model. This then forms part of the full CVS model used to appraise the design in a vehicle impact. However the time required for prototypes to be created and tested limits the advantages of using the CVS technique.

With the application of the nonlinear FE technique suitable data can be obtained at an early stage in the design process, before any wheels are available. The main design loop can then rely entirely upon analytical methods for the evolution of the design features. As such, it can be invoked repeatedly over a relatively short period of time. A further advantage to be explored is that the same FE model can also be used to investigate other design parameters such as static strength and NVH performance.

Some types of foam covering have a significant effect on impact performance, and it will be necessary to model the foam completely in the FE model. This is especially important for extending the model to predict performance in the 'soft face' impactor tests.

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Facial Injury Occurrence in Traffic Accidents and Its Detection by a Load Sensing Face

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Abstract

Head and facial injuries are becoming less frequent and less severe in modern day cars. Volvo has conducted accident research with respect to frequency, location and severity. Comparisons between belted drivers and front seat passengers are made. Only about 6 percent of the passengers that sustained some kind of injury had a facial injury. The corresponding figure for the driver was 10 percent. With respect to fracture and contusion, the following facial areas emerged as the most often injured: nasal region, forehead and mandible.

The fracture and contusion type injuries can be detected by using a new load sensing face with piezo electric sensors. This face was subjected to some P572 calibration tests with results similar to those obtained with a standard Hybrid II head. The face was mounted on a Hybrid II dummy and subjected to sled testing. The kinematics were not affected by the umbilical cables etc. Consequently, the face can be used in normal testing without significantly affecting other measured safety parameters such as the HIC. Also, for future biomechanical research to establish injury criteria, the load sensing face promises to be a helpful tool.

Introduction

Facial injuries are becoming more important in car safety design. This does not mean that the number or severity of injuries in the face are increasing. In fact, they are both decreasing as a consequence of improved restraint systems, improved car interior design, the increasing number of seat belt wearers, etc. However, it has not been possible to totally eliminate facial injuries. The proportion of the less severe injuries in the facial area is therefore growing, which must be accounted for by new test methods in product safety development.

Head injuries have traditionally been divided into two different groups depending on the injury mechanism, i.e. acceleration and pressure induced trauma, figure 1.

Hitherto, most safety research has concentrated on the severe head injuries. These could be detected by means of acceleration levels measured at the center of gravity of the head. Federal Motor Vehicle Safety

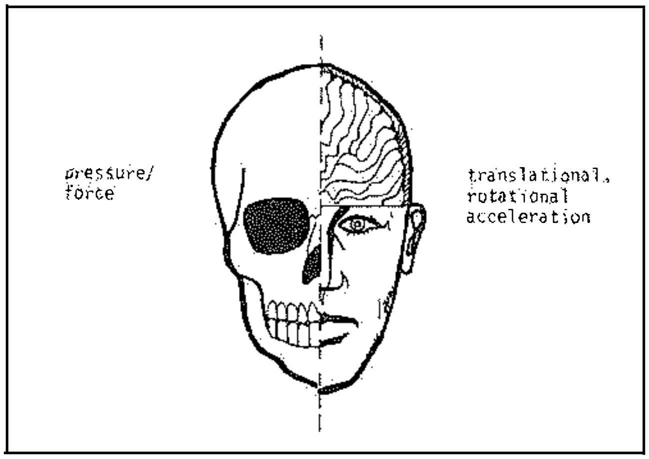

Figure 1. Injury mechanisms

Standard (FMVSS) 208 utilizes this method(1,2,3,4 and 5). Another method used is the rotational acceleration measurement.

The less severe head injuries, for example fractures of different facial bones, have until recently not been possible to measure. Here, the force or pressure applied must be evaluated. Various attempts have been made; deformable foam systems and strain gage force transducers are only two of several methods(6, 7 and 8). However, these methods have proved insufficient.

A load sensing face that utilizes thin piezoelectric pressure sensitive films was developed and presented by Volvo in 1986(9), figure 2. The dummy facial area is covered by 52 of these sensors, each measuring the force applied to the different facial segments. An on-board data acquisition system stores the data from all sensors. After the test, a host computer retrieves the data and presents the force—time histories from each individual sensor. The load sensing face can be used to associate the applied force with facial bone fractures and other connected injuries such as contusions.

This paper presents the load sensing face and two studies that were carried out in parallel. The first part of the paper deals with the Volvo accident material and the information we have obtained from in-depth accident studies. Laboratory use of the load sensing face, including calibration and some dynamic testing, is discussed in the second part.

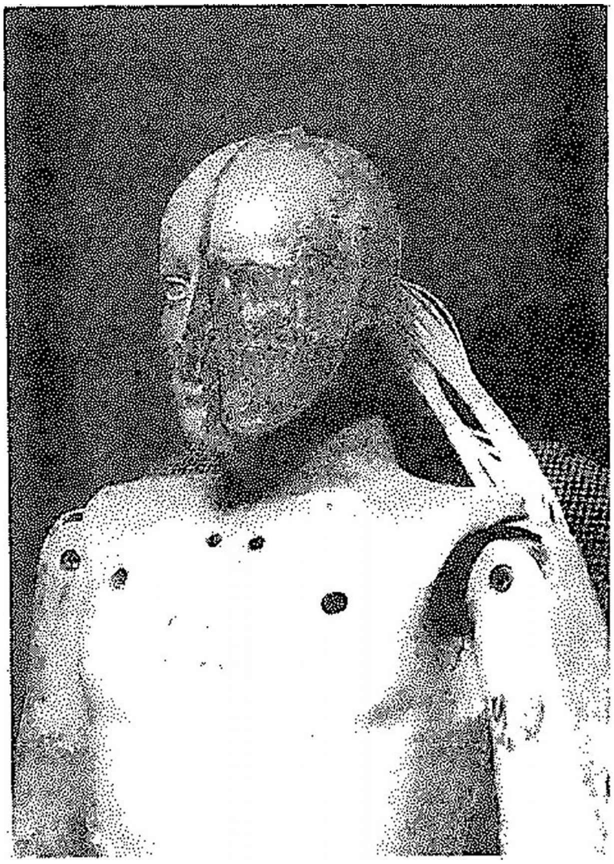

Figure 2. The load sensing face

Accident Knowledge

An accident study was made to try to answer the following questions regarding facial injuries:

- what is the proportion of severe to moderate injuries?
- which facial regions are most often injured?
- is there a difference between driver and passenger?

The studied sample was selected from a database of accident material, sampled according to a cost repair criterion(10), i.e. tow-away accidents. In the material both injured and uninjured persons, altogether 15,000 occupants, are represented. The sample mainly contains belted occupants. The unbelted frontseat drivers and passengers only add up to 6-7 percent. A statistically significant conclusion is thus not possible to draw from this unbelted group. The impact direction chosen to study is frontal to oblique/frontal (11 to 1 o'clock). The structure of the material chosen for the accident study is shown in Appendix I.

Driver Accident Analysis

Volvo's analysis showed that approximately 10 percent of the belted drivers that were injured in frontal to oblique/frontal accidents sustained injuries in the facial area.

In order to obtain a proportional assessment of driver facial injuries, the severity of the injuries was assigned to an appropriate level in the Abbreviated Injury Scale (AIS). The result is shown in table 1.

It can be noted that the majority of the facial injuries was coded AIS 1 and to some extent by AIS 2.

The driver facial injuries were then studied to establish which region had been injured. The injuries were divided into groups; laceration, abrasion, contusion, fracture and others. We found that the less severe lacerations dominated the number of injuries. The most complicated of these injuries, the fractures and the contusions, are presented from a severity, a

Table 1. Facial injury proportion of belted injured drivers and passengers.

AIS	Proportion (%)	
	Driver	Passenger
1	77	85
2	17	11
3	5	4
4	1	0
5	approx. 0	0
6	0	0
Total	100	100

locational, and a proportional point of view in figure 3.

Passenger Accident Analysis

Investigation of passenger statistics shows that less than 6 percent of the belted passengers injured in frontal to oblique/frontal accidents sustained injuries in the facial area.

Table 1 shows that the facial injuries of the passengers did not exceed the AIS level of 3 at all, and only 4 percent of them exceeded AIS 2.

An investigation to study facial regional differences, corresponding to the driver study, was performed. It showed that also among the passengers, the less severe lacerations were dominating. Fractures occurred in even fewer cases than among the drivers. Figure 4 shows the distribution of the contusions and fractures.

Comparison Driver and Passenger

Compared with the drivers, the front seat passengers sustained less frequent and less severe injuries. This can be explained by the absence of a steering wheel, and thus a longer available deceleration distance for the passenger.

While the steering wheel can be said to be the main impact area for the driver, the instrument panel is the region most frequently hit by the passenger. This probably explains the reversed ranking between the frontal and the nasal area for driver and passenger respectively.

Injuries lower down the face, such as the mandible area, are as frequent among the passengers as among the drivers regarding the percentage. Counted by numbers, however, these injuries occur as rather unusual for the passenger category. This is probably due to a lesser likelihood of any impact at all because of the limited vertical extension of the instrument panel compared with that of the steering wheel.

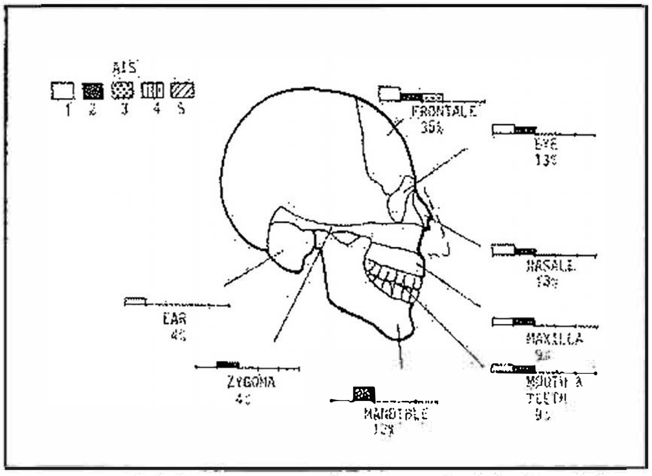

Figure 3. Driver facial injuries; fracture and contusion

Injury Coding

The analysis revealed that the majority of facial injuries is coded by the lowest AIS levels. Some examples of injury coding for different AIS levels are as follows: AIS 1 is ascribed to a fractured tooth, a smaller hemathoma in the forehead etc. The facial injuries coded AIS 2 include a fracture through the nasal bone without displacement. Mandible fractures are coded AIS 1-2. Bilateral fractures of the zygomatic bones or the maxillary bone in accordance with Lefort III are injuries which can have an AIS value of 3.

The AIS scale(11) is mainly a means of estimating the threat to life risk. The AIS in its present form, however, does not adequately measure the level of disability or the actual harm sustained by the individual. A disability scale that would complement the AIS and provide the link between injury assessment and societal costs is being pursued.

Injury Detection

Two of the injury types described above, laceration and abrasion, can be detected using chamois skin. Lacerations of the skin covering the dummy face are judged with respect to the number of lacerations, depth and length. The outcome of this is a figure which should correspond to an actual laceration pattern in real life. The other two injury types, contusion and fracture, can be measured by the load sensing face.

Injury Thresholds

The various areas of the face are significantly different with respect to anatomical design, strength of the facial bone and the overlying soft tissue. Combined, this presents a complicated problem, i.e. the injury thresholds differ substantially. The thresholds are also dependent upon how the force is

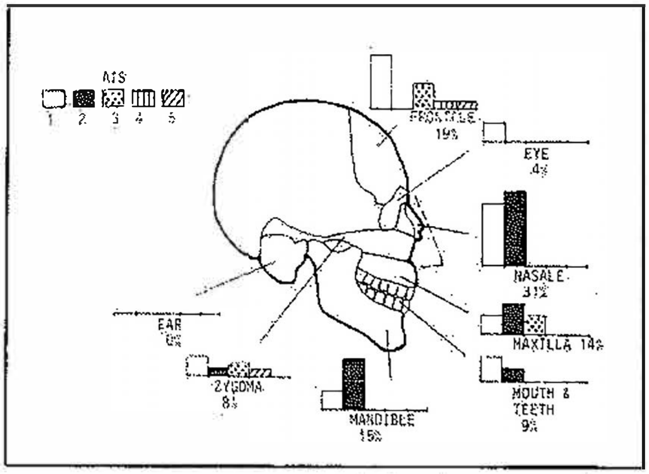

Figure 4. Passenger facial injuries; fracture and contusion

applied. One should take into account both the impacted surface characteristics, as well as the impact direction, the specific pressure and the duration of the force subjected to the face.

The effect of the impact speed has not been fully examined, most biomechanical researchers have used impact speeds typically below 10 m/s. The reported research has also concentrated on impacts on various facial bones, but the effects from an overall pressure has seldom been studied. The impacted surfaces have mostly been of a rigid, sharp design that is not representative of steering wheels, instrument panels or other interior parts of today's cars.

Research by Nahum (12), Schneider (13), Tarriere (14) and others have provided us with injury thresholds for different facial segments. However, these values are not correlated to a pressure or force registered by some kind of recorder, such as a dummy head, used for measuring car interior impacts during crash testing. We believe that the load sensing face is an excellent tool to evaluate injury thresholds and that it can find extensive use in future biomechanical research. This correlation between biomechanical data and measured parameters such as force or pressure to the facial segments, is necessary to make it possible to understand how to further improve the interior safety design.

Laboratory Experience With the Load Sensing Face

The prototype load sensing face is derived from a Hybrid II head(9). The attachments of the piezoelectric pressure sensitive sensors, the umbilical cables etc, were all chosen not to significantly change the characteristics of the head. In order to evaluate the possible differences between the load sensing face and the standard Hybrid II head, it was subjected to various tests.

Calibration and Validation

The FMVSS 208 P572.6 and P572.7 procedures were used as a basis for studying the suitability of the load sensing face as a test instrument.

Mass. The mass of the prototype head including skin and a 3 axis accelerometer is 4.93 kg. This can be compared with the 4.54 + – 0.04 kg that a standard Hybrid II head weighs. The excess of the load sensing face, 0.39 kg, can be lowered in future head designs by using other, lighter materials and thus bringing the weight within acceptable levels.

Center of Gravity. The electrical cable from each sensor is lead to a junction box positioned in the skull cavity shown in figure 5. This slightly alters the center of gravity for the head. The c.o.g. in the horizontal-vertical plane is moved 9 mm forward and 12 mm upward. This can be considered an acceptable change of the c.o.g.

Table 2. Head drop tests.

Test	Resultant acceleration (m/s^2)	Pulse duration at 981 m/s^2 (ms)	Unimodal curve	Lateral acceleration (m/s^2)
Load sensing face				
Test 1	2509	1.28	Yes	- 51.8
Test 2	2683	1.15	Yes	- 56.9
Test 3	2686	1.15	Yes	- 95.5
Standard Hybrid II				
Test 1	2682	1.28	Yes	-168.9
Test 2	2733	1.28	Yes	- 34.2
Test 3	2762	1.15	Yes	67.8
Requirements	2060 to 2551	0.90 to 1.50	Yes	- 98.1 to 98.1

The Polar Moment of Inertia. The polar moment of inertia of the head with skin cover was also measured to check the mass properties. For the lateral y-axis the polar moment was measured to be Iy = 0.0243 kg m2. Published values for an average Iy of 0.0233 kg m2(15) for cadavers indicate that the load sensing face has good inertial equivalence.

Head Drop Tests. Matched head drop tests were performed with the load sensing face and a standard Hybrid II head as a reference. Both heads used the same PVC skin to be able to compare only the skulls themselves. Three tests were made with each head. The results are summarized in table 2.

As can be seen from table 2, the load sensing face meets the requirements except for the resultant acceleration in two tests, where the values are slightly over the specified range. However, since the standard Hybrid II head we used exceeded the limit in all three tests, the load sensing face can be regarded as fairly close to the requirements. Also, with some allowable modifications of the skin-skull friction coefficient, this would probably move the measurements into the desirable range.

Neck Pendulum Test. Neck pendulum tests were performed with the load sensing face and a standard Hybrid II head. The neck and the PVC skin were the

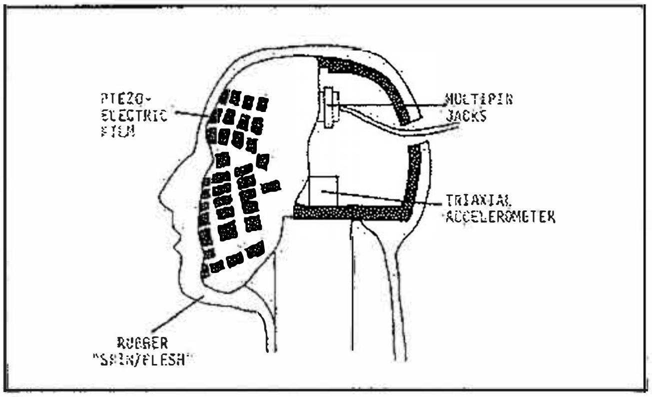

Figure 5. Schematic view; the load sensing face

Table 3. Neck pendulum tests.

Test	Res. acc. (m/s²)	Max. Rotation (degrees)	Time at max.rot (ms)	Max.chordal displacement (mm)
Load sensing face				
Test 1	287	65	52.6	135.5
Test 2	279	65	53.0	134.6
Test 3	286	66	53.2	135.2
Standard Hybrid II				
Test 1	293	62	53.8	128.4
Test 2	293	62	53.5	127.3
Test 3	287	62	53.4	127.0
Requirements	max. 255	63-73	53.2-66.6	127.0-152.4

same for both heads, only the skulls were shifted. Both neck and PVC skin were new and had not been used in earlier tests. Three tests were performed with each head. The results are summarized in table 3.

Table 3 shows that the load sensing face meets the requirements concerning maximum rotation and maximum chordal displacement. The resultant acceleration shows higher values than are required, but these values are even higher for a Standard Hybrid II head. The requirements will possibly be met for both dummies if the neck is changed.

The higher values of the chordal displacement for the load sensing face will allow the straight line motion of the head's center of gravity relative to its initial point to be longer than for the Hybrid II head. Thus, when interpreting the results of a test, it should be born in mind that the degree of severity will appear somewhat higher for the load sensing face in its present form than for the Standard Hybrid II.

Temperature Sensitivity. The load sensing face is designed to provide accurate readings in the 22 +- 11 degrees Centigrade temperature interval. Since the FMVSS 208 requires the stabilized temperature of the test equipment to be between 18.9 and 25.6 degrees Centigrade for Hybrid II testing, the face should work well in the laboratory. This is also the case in Hybrid III tests, where the allowed temperature is between 20.6 and 22.2 degrees Centigrade.

Testing

In future routinely performed crash testing one can distinguish at least three different ways of using the load sensing face: barrier crash testing, sled testing and component testing. The outcome from two of these test methods, the sled and the drop test, will be discussed below.

Sensor Calibration. Before testing, the face has to be calibrated. This is performed inside a hydro dynamic chamber. The face is protected by a rubber boot and placed inside the chamber. All sensors and a reference strain gage are subjected simultaneously to a steep pressure pulse, supplied by inert gas. The data acquisition system compares each individual sensor with the reference pressure and correction factors are computed. The corrections are due to zero offset, charge leakage and scale factors. After calculation they are stored in a file of individual sets of calibration factors for each sensor to be used later for evaluation of impact data(9).

Dynamic Testing. The aim of the first test runs was to provide answers to the following questions:

- what are the effects on the dummy kinematics due to the umbilical cables attached to the dummy head?
- how does the onboard MDAS (Modular Data Acquisition System), designed to withstand high g-levels, function during the crash simulation?

A Volvo car body, from the 700 series, was mounted onto the sled. A Hybrid II dummy, equipped with the load sensing face, was positioned in the passenger position. It was restrained by a three point belt. The sled was then subjected to a simulated 30 mph barrier crash. High speed films were used to check the dummy trajectory. The umbilical cables were routed out of the back of the dummy skull (figure 7). The connections to the multipin jacks inside the skull cavity were secured by means of a steel plate that was fastened by two bolts. Enough slack in the cables was provided to ensure that these did not limit the movement of the dummy. An extra amount of cables was positioned behind the back of the dummy to allow for upper torso displacement during the crash event.

Pre-test preparation also included examination of the MDAS box to establish what precautions were necessary in order to prevent any damage resulting from high g-levels. The power supply unit, which is

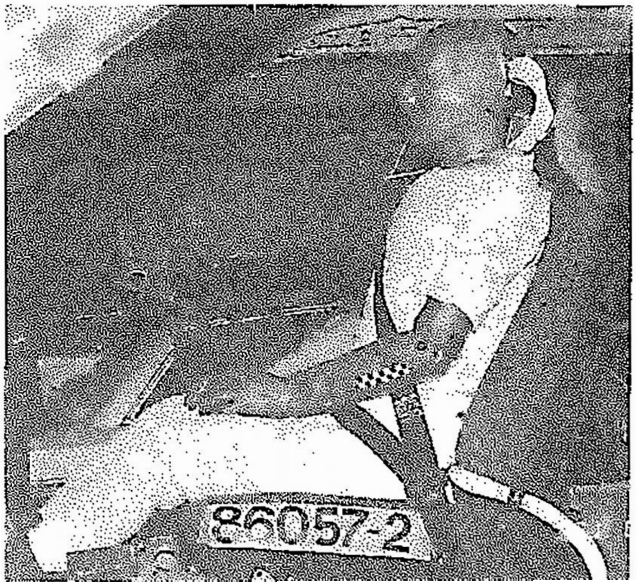

Figure 6. Pre test; sled testing

the heaviest part of the MDAS box, was secured inside the MDAS shell by means of sheet metal support and rubber padding. The MDAS unit was dismounted after the two tests and checked for any damage.

The MDAS box itself was positioned in the longitudinal direction of the car in order to have the lowest possible strain to the MDAS internal electronics. The box was attached to the floor by means of rubber cylinders (figure 8). The whole unit was mounted in an area behind the front seat.

Sled Test Evaluation. Tests were made with a dummy complete with the load sensing face and its cables. A series with a standard Hybrid II head was also performed for comparative reasons.

Although few tests were made, it seems that no major difference in dummy trajectory at the c.o.g. of the head will appear. This will be further studied in future sled testing.

For future applications the cables from the load sensing face will be improved in the following ways:

- the thickness and stiffness of the cables can be reduced to some extent
- the cables will be routed out of the base of the skull to be parallel to the vertical axis of the neck

Both countermeasures will even further lessen the resulting effect from the cables. Then the acceleration signal from the center of gravity of the head will not be affected, which means that the HIC calculation can be compared with tests utilizing a standard Hybrid II dummy head.

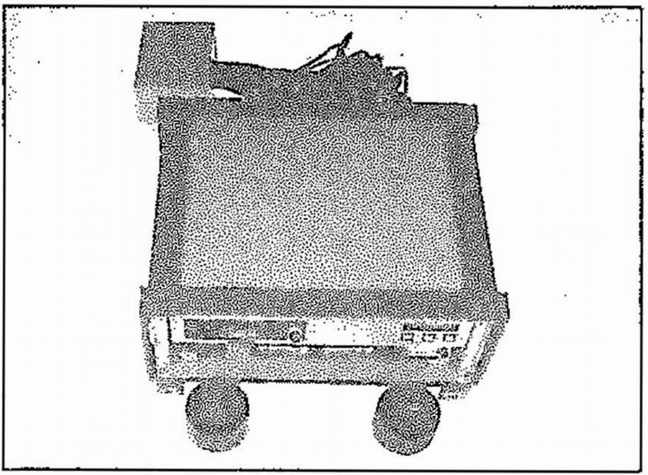

Figure 8. MDAS protection box

The MDAS box sustained some damage in the latter part of the test series. To avoid this, and also to be able to run tests at higher speeds, the g-force resistance preparation has to be improved.

The load sensing face can also be used in component testing in a drop test device, figure 9.

This method is applicable when testing steering wheels, instrument panels or other interior components. It enables the test engineer to have a simple and inexpensive method to make a coarse evaluation of the safety performance.

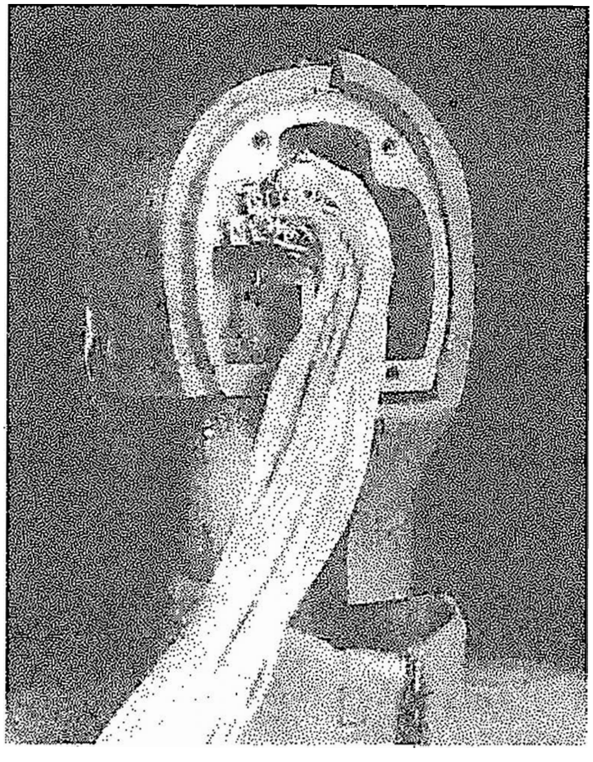

Figure 7. Cable attachments; back plate removed

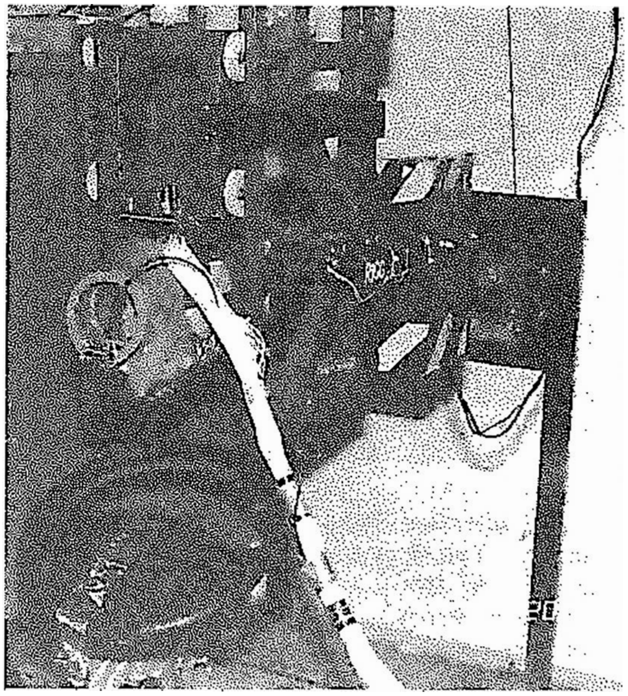

Figure 9. Component testing; impact against steering wheel

Hybrid III Prototype

In the first prototype of the load sensing face 52 sensors covered the facial region. These sensors were mounted rather uniformly over the dummy face.

From preliminary testing with the head form we have found that the number of sensors, 52, involves unnecessary long computer time and that after testing, the time for analysis by the test engineer has increased. To be able to use the load sensing face in routine testing, the number of sensors should be decreased. This, however, must be reached without losing the detailed picture of the sustained facial violence.

From our accident survey, we know that four facial areas are of special interest: the nasal region, the forehead, the maxilla and the mandible. A new sensor configuration should at least cover these areas.

A Hybrid III prototype with only half of the number of sensors used in the previous prototype has therefore been designed. The new sensor location is based on the principle that neighbouring areas with equal resistance to impact and with similar curvature can be covered by the same sensor.

The conclusions above are derived from accident statistics obtained mainly from frontal and oblique/frontal impacts (11 to 1 o'clock). Consequently, if, for example, side impacts were to be studied, the sensor location would probably be somewhat different. If the face is to be used in side impact testing, the temple region should be covered with sensors to a greater extent.

Future Development

The load sensing face is currently undergoing further testing.

The hardware equipment, such as the MDAS unit and the umbilical cables will be further improved. The aim is to withstand higher g-forces and also to limit the effect on dummy movement.

Computer software will be developed in order to make the facial forces easy to survey.

An attempt will be made to simulate the nose and the structure underlying it. This could be obtained by using a frangible insert for one-time use only which can be changed without removing flesh and head from the dummy.

Summary

Even though the facial injuries in the accident statistics are few and minor, there is clearly a need for a device that can measure facial injuries. The load sensing face developed by Volvo detects fracture and contusion type injuries.

Accident research done by Volvo includes injury types and injury severity for both belted drivers and front seat passengers. Of the occupants sustaining some sort of body injury, only 10 percent of the drivers and 6 percent of the passengers sustained a facial injury. Of the facial injuries the majority was coded AIS 1-2. Some small differences were seen between the driver and the passenger, both with respect to injury frequency as well as to facial location.

The face can be used in both crash and sled testing with complete dummies as well as in component testing. Calibration tests of the head, including drop-test, mass properties, etc., together with some limited dynamic sled testing indicates that the load sensing face does not particularly alter the Hybrid II head characteristics. The extra equipment—umbilical cables, etc.—do not significantly affect the dummy kinematics.

For future biomechanical research to establish injury criteria the load sensing face promises to be an excellent tool. Correlation between injuries and forces measured by the face is necessary, so that knowledge can be gained to further improve interior safety design.

Acknowledgements

The work presented here is the result of the research and deliberations of many persons. We would particularly like to acknowledge Prof. Charles Y. Warner of Collision Safety Engineering and Dr. Milton G. Wille of Brigham Young University who made the development work on the load sensing face. We also wish to thank Agneta Ebbesson for her contribution to the calibration and comparison of the load sensing face and the Standard Hybrid II head. The authors would also like to thank Johnny Korner for his help in the accident study.

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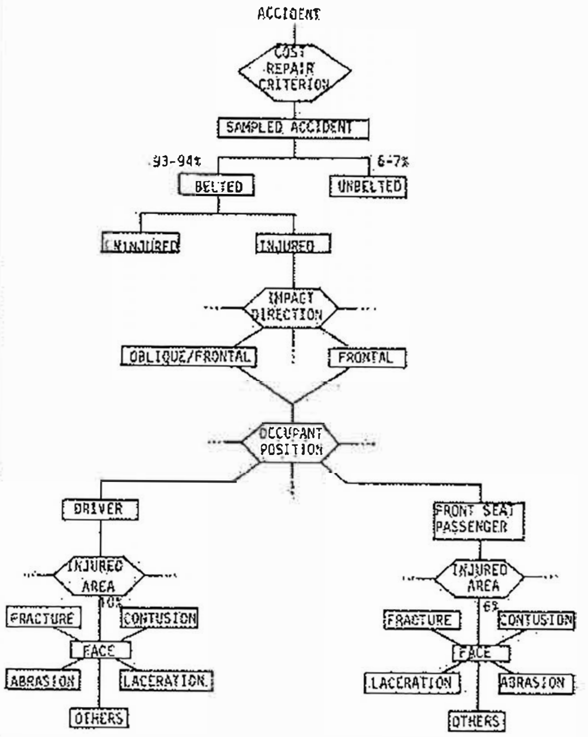
Appendix 1



Flow chart, accident sample

The Child in the Volvo Car

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Abstract

The objective of this report is to describe Volvo's development work in the field of child safety. Experience from car accidents involving children is used to describe different modes of travel for children of different age groups, the effectiveness of different child restraint systems and problems of misuse.

The problems of differences in the requirements of child safety legislation are discussed.

This experience combined with experience gained from laboratory tests constitutes the basis for development work on child safety systems in Volvo cars.

Volvo's new child safety program covers all age groups of children and needs for different ways of travel.

Volvo Safety Design Philosophy

To Volvo, safety has always meant safe transportation in a real traffic environment. Volvo Safety Design Philosophy can be illustrated by a circle as in Figure 1.