A SIMULATION STUDY ON INFLATION INDUCED INJURY AND NCAP WITH DEPOWERED AIR BAG

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ABSTRACT

In the United States, air bags are required in all passenger cars and light trucks. The National Highway Traffic Safety Administration (NHTSA) has estimated that almost 2,800 lives have been saved by the air bags. However, air bags designed to protect passengers have, in some situations, caused serious injuries, especially in moderate impacts. Last year, in order to reduce injuries caused by air bag inflation, NHTSA revised the requirements for FMVSS 208 unbelted testing to allow the sled test protocol as a temporary alternative to the frontal barrier vehicle crash test. It is believed that this decision will allow manufacturers to depower air bags by about 20-35 percent, decreasing aggressiveness of air bags during inflation. The NHTSA continues to use the New Car Assessment Program (NCAP) 35mph frontal barrier test as a "measure" of vehicle crashworthiness. The NCAP test report data are widely disseminated to the public as vehicle safety information.

This paper evaluates the effects of air bag depowering on dummy measurements under both moderate frontal impact and severe 35mph frontal barrier impact using MADYMO simulations. These simulations suggest that the aggressiveness of the air bag deployment can be greatly reduced in moderate impacts, without compromising occupant protection performance in more severe impacts.

INTRODUCTION

About a quarter century has passed since air bags were first offered on a few vehicles in the 1970s. NHTSA has required air bags on the driver side from 1991, and on both the driver and passenger sides from 1998. There has been high consumer demand for air bags, and consequently automobile manufacturers have actively introduced new vehicles equipped with air bags. According to the data published on Feb. 1, 1998, by NHTSA, in the United States 70.6 million vehicles (48.6 million passenger cars and 22 million light trucks) are equipped with air bags. In this report, NHTSA estimates that 2,474 drivers' and 370 passengers' lives have been saved by air bags. However, it is also reported that air bags designed to protect occupants have induced some serious injuries, especially in crashes of moderate impact. The Special Crash Investigation (SCI) showed that 37 drivers, 13 children in rear facing child safety seats, 42 children not in rear facing child safety seats, and 4 adult passengers were killed by air bags. These reports led to an increase in public awareness that air bag may cause unnecessary automobile fatalities. As a result, in March 1997, NHTSA revised the requirements for FMVSS 208 unbelted testing to allow the sled test protocol as a temporary alternative to the frontal barrier vehicle crash test. In November 1997, NHTSA also allowed cut-off switches for short stature drivers and other occupants deemed at-risk by the agency. As of April 1998, an estimated 22,000 users have obtained permission to install these switches to deactivate the air bags in their cars.

OBJECTIVE

The first aim of this study is to clarify that depowering of the driver side air bag reduces its aggressiveness, and the second aim is to demonstrate how occupant protection performance is influenced by depowering of air bags, which are designed as a supplemental restraint system, using MADYMO simulations. For the air bag aggressiveness study, a moderate impact condition was used in the MADYMO simulations. For the occupant protection study, a severe frontal barrier crash test was selected to assess occupant protection performance in the consumer information NCAP test. Finally, we investigated occupant protection performance using HIC(15) and chest deflection, which are more suitable criteria of occupant protection than HIC(36) and chest g's, especially in cases where occupants are restrained by both air bags and seat belts.

MADYMO Simulation Study

Moderate Frontal Impact Model - To evaluate the air bag deployment and its relative aggressiveness, we carried out MADYMO(Ver. 5.2) simulations. As mentioned above, a moderate frontal impact was selected for this study. The model had no intrusion of either the steering column or the toe board, and the deceleration of a vehicle in a moderate barrier frontal crash was used (Figure 1). The TNO original AF-05 dummy database was used for the driver dummy and the seat was placed in the most forward position in these cases. FEM seat belt models were used instead of conventional belt models. Depowering of the air bag was modeled by reducing mass flow rate. As shown in Figure 2, air bag "B" was about 20 percent depowered, compared with air bag "A." Graphic output from the simulation using air bag "A" (Figure 3) demonstrates that the dummy experiences hyper-extension of its neck as the air bag deploys. However, the simulation with the depowered air bags shows the dummy sustaining less hyper-extension, relative to the baseline air bag (Figure 4). In addition, HIC (36), chest g's, and the neck extension moment were all reduced by air bag depowering (Figure 5, 6, and 7).

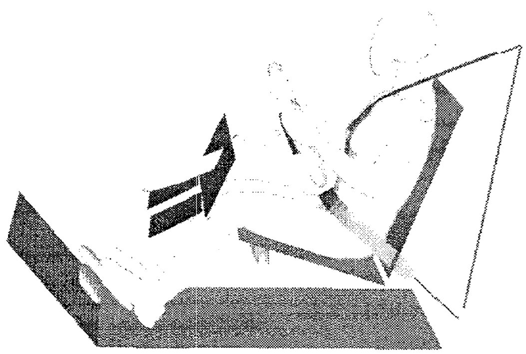


Figure 1. MADYMO Model in Moderate Impact.

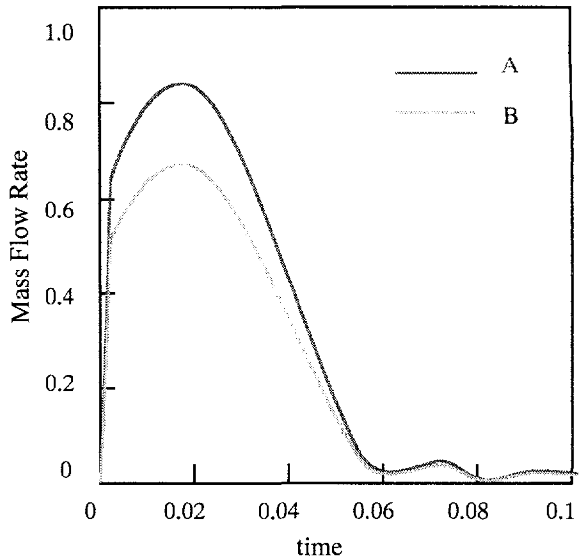


Figure 2. Comparison of Mass Flow Rate.

Severe Frontal Impact Model - Using the same models for baseline and depowered air bags as in the previous study, we carried out MADYMO simulations under a 35mph frontal impact condition. However, the dummy database was changed from the TNO original AF05 to the TNO original AM50, and 2 different seat belt systems were used in these simulations. The AM50 dummy was seated according to FMVSS 208 test procedures. One seat belt was modeled as being equipped with a conventional retractor, and the other was modeled as being equipped with both a pretensioner and a force limiter. The level of limiting force was about 4 kN. Figure 7 shows graphic output of the simulation with air bag "B", pretensioner and force limiter. Figures 9-12 show comparisons of dummy measurements, HIC(36), HIC(15), chest g's, and chest deflection. Results show that a change from air bag "A" to air bag "B" produced somewhat higher HIC scores, but the addition of the pretensioner and the force limiter reduced the dummy measurements.

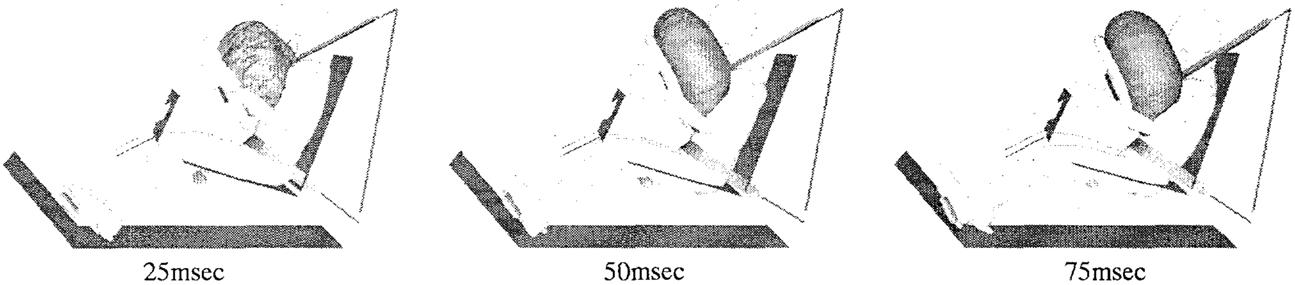


Figure 3. Graphic Output of MADYMO Simulation in case of Air Bag "A".

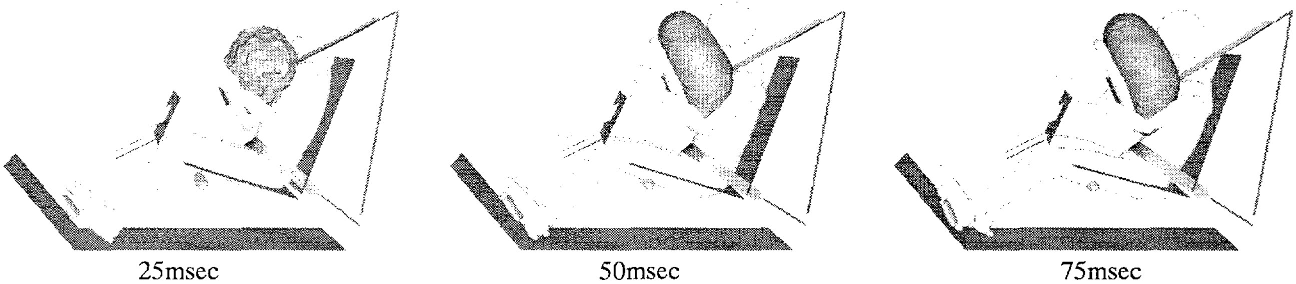


Figure 4. Graphic Output of MADYMO Simulation in case of Air Bag "B".

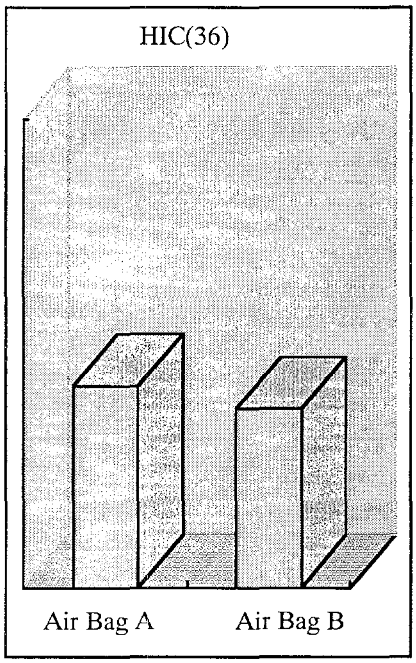


Figure 5. HIC(36) of MADYMO Simulation.

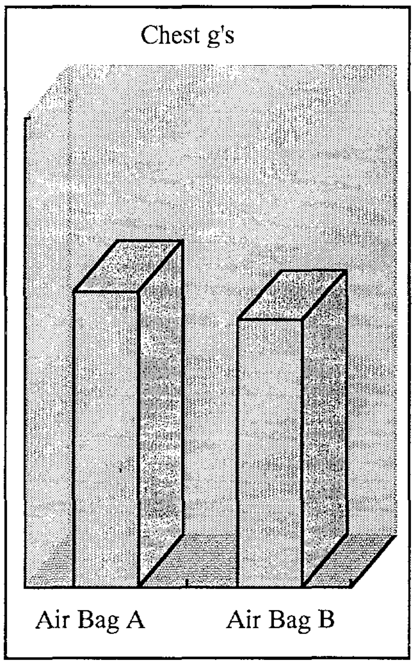


Figure 6. Chest g's of MADYMO Simulation.

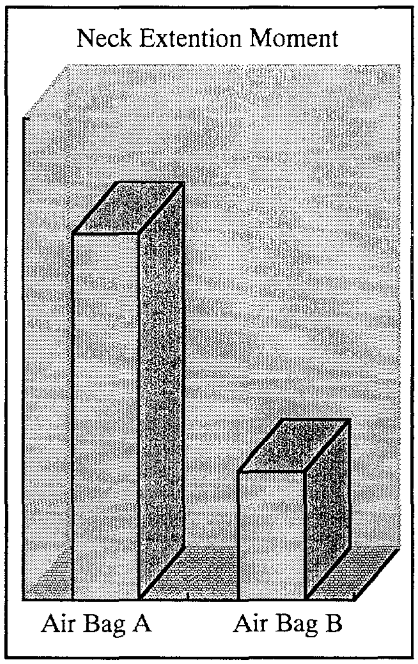


Figure 7. Neck Extension Moment of MADYMO Simulation.

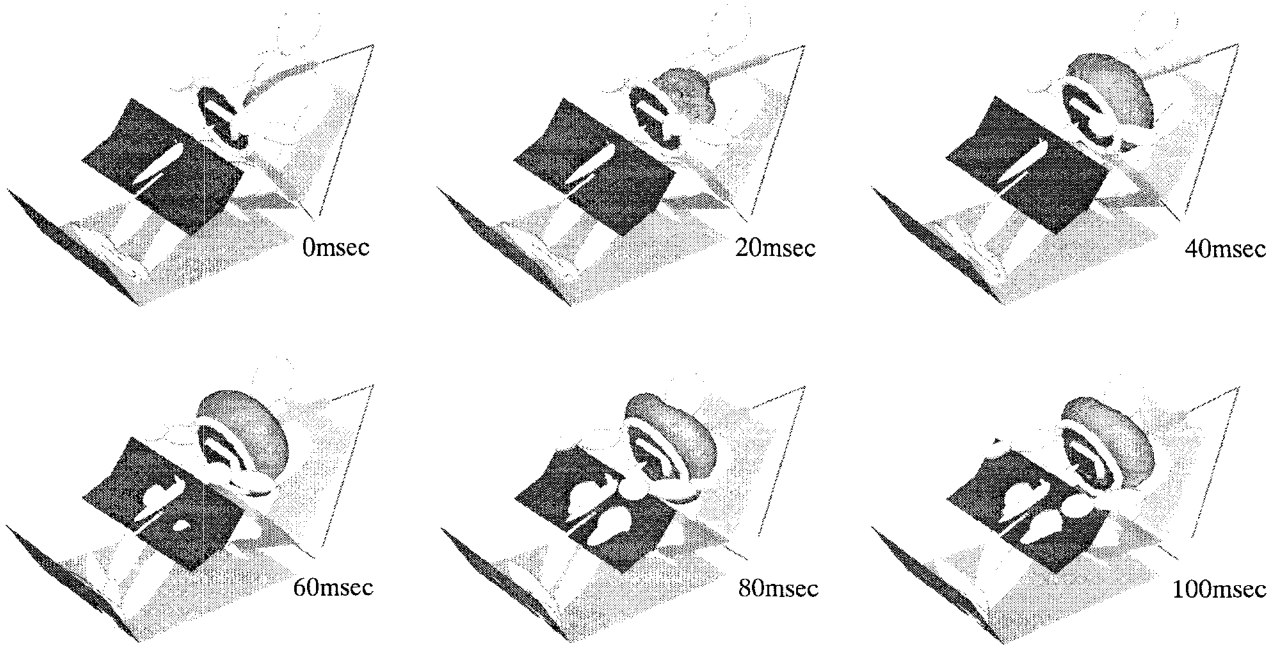


Figure 8. Graphic Output of MADYMO Simulation in case of Air Bag "B" with Pretensioner and Force Limiter.

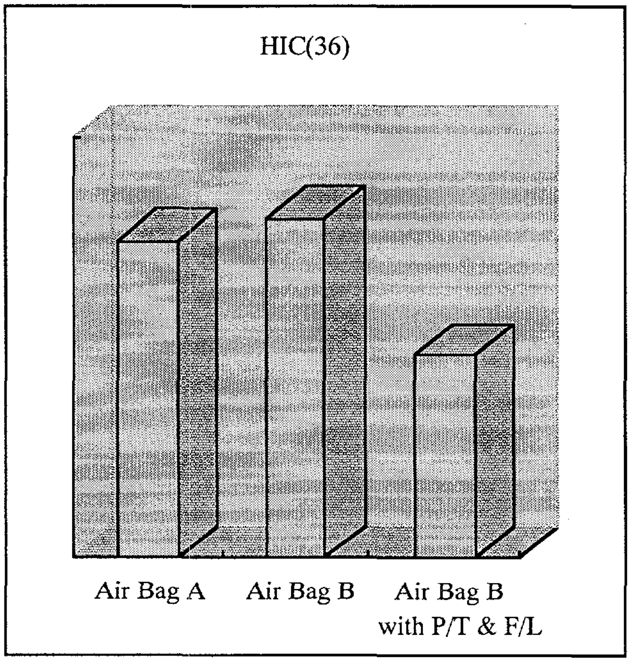


Figure 9. HIC(36) of MADYMO Simulation.

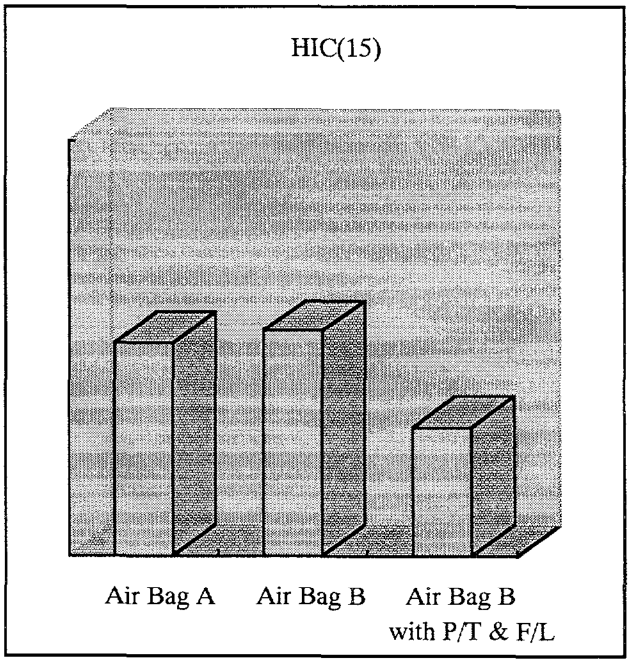


Figure 10. HIC(15) of MADYMO Simulation.

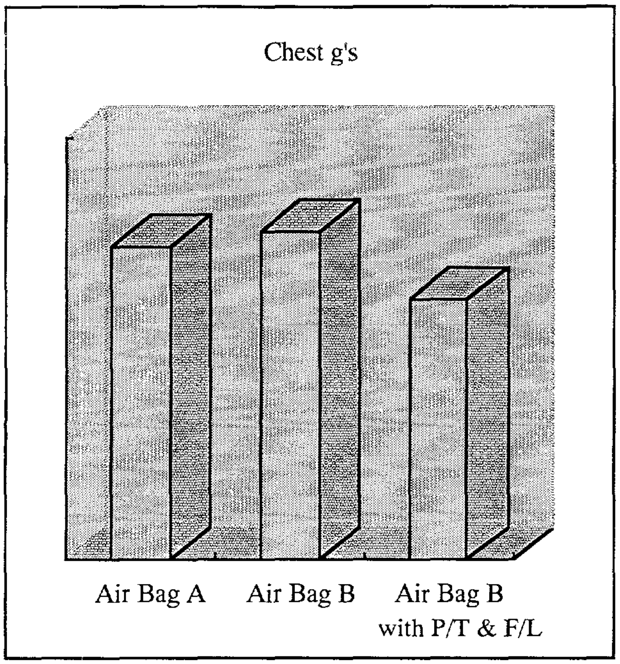


Figure 11. Chest g's of MADYMO Simulation.

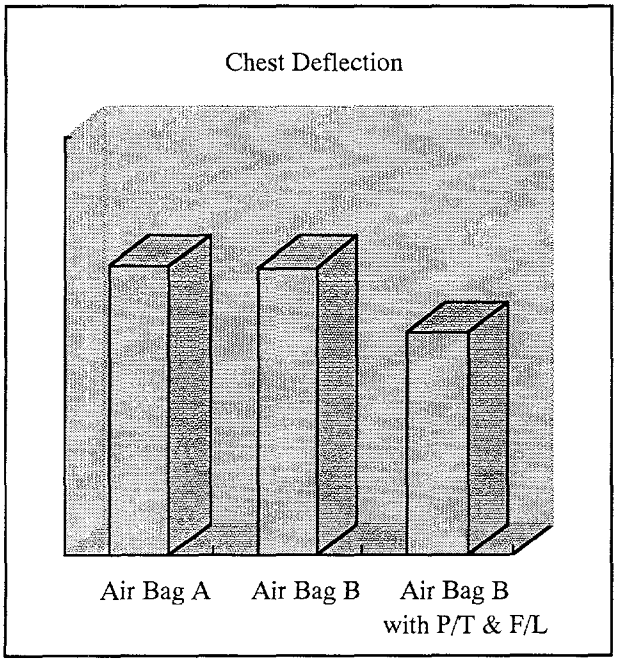


Figure 12. Chest Deflection of MADYMO Simulation.

DISCUSSION

The results of the MADYMO simulations indicated that depowering of air bags reduces aggressiveness under a moderate impact condition. It is also showed that depowered air bags may produce slightly higher dummy measurements than baseline air bags in MADYMO simulations of a 35mph frontal impact. NHTSA has also conducted a MADYMO simulation study evaluating air bag aggressiveness, and their results were published in the Final Regulatory Evaluation in Feb. 1997. The report included the results of 35mph frontal impact vehicle tests with AM50 dummy restrained by both the air bag and the seat belt. The vehicle tests and MADYMO simulations conducted by NHTSA showed the same tendency as our results (Table 1 and Table 2). Based on these results, they concluded that air bag depowering makes little difference on HIC and chest g's in the 35mph frontal tests.

On the other hand, various crash tests, whose results are widely reported, are currently carried out to produce vehicle safety information for consumers. As shown in Tables 3 and 4, many of these ratings are based on HIC(36) and chest g's (which are used for injury criteria

Table 1.
Vehicle to Barrier Tests by NHTSA

	Baseline	25% Depowered
HIC	814	857
Chest g's	52	59.6

Table 2.
Simulations by NHTSA

	Baseline	20% Depowered
HIC(36)	600.5	678.5
Chest g's	42.3	44.6

Table 3.
Various Rating Test Conditions

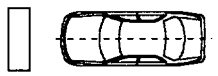
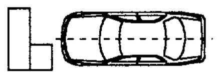
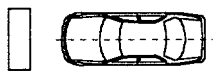
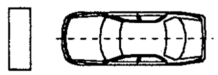
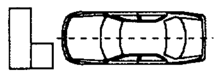
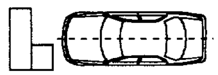
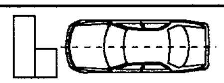
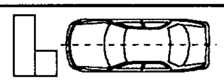
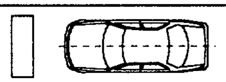
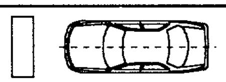
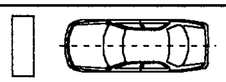
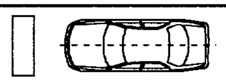
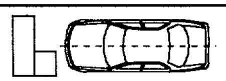
		Configuration	Impact Velocity	Dummy	Measurements						
					Head				Chest		
					HIC(36)	HIC(15)	3msG	peakG	3msG	Deflection	V*C
United States	NHTSA		35mph	H-Ⅲ	○				○		
	IIHS		40mph		○	○	○	○	○	○	○
Japan	MOT		55kph		○				○		
Australia	Queensland, NSW, South Australia		56kph		○				○		
			64kph								
United Kingdom	TRL		64kph		○		○	○		○	○
Germany	AMS		55kph		○		○		○		
	ADAC		60kph		○		○		○		

Table 4.
Compliance Test Conditions

	Configuration	Impact Velocity	Dummy	Measurements						
				Head				Chest		
				HIC(36)	HIC(15)	3msG	peakG	3msG	Deflection	V*C
United States		30mph	H-Ⅲ	○				○	○	
Canada		30mph			○		○		○	
Japan		50kph		○				○		
Australia		50kph		○				○	○	
Europe		56kph		○*		○			○	○

* in case with head contact only

in most compliance tests as well).

The concept of HIC was proposed by Versace in 1971. It is a value based upon the head acceleration vs. time curve. In 1972, NHTSA proposed the use of HIC for assessing the potential of head injury with HIC < 1000 being acceptable values. In 1986, NHTSA proposed a time limitation of 36msec for calculating HIC value. This limitation was applied because high HIC values were being produced by low acceleration of long duration. That did not represent a likelihood of head injury. At that time, two alternative methods of HIC calculation were proposed. The first was to calculate HIC for the duration of head contact only. This option was rejected because of the difficulty in measuring the head contact duration. The second alternative was to set a limit for the time duration during which HIC is calculated. Although a number of researchers had proposed to use a time limitation in the order of 15-17msec, NHTSA finally selected 36msec as the time limitation to be used for HIC calculation based on their study. Prasad and Mertz proposed HIC(15) and also developed a life-threatening brain injury risk curve based on an analysis of HIC(15) values. The method of calculating HIC(15) has been accepted by the International Standards Organization. We calculated HIC(15) values using head resultant acceleration of MADYMO simulations for the 35mph frontal impact.

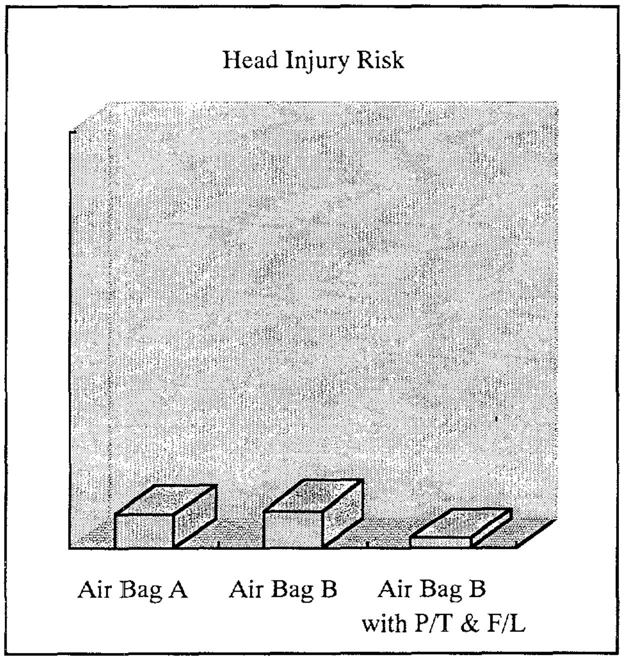


Figure 13. Head Injury Risk of MADYMO Simulation.

The injury risk of each simulation was calculated and charted using the Prasad and Mertz curve (Figure 13). A comparison of injury risk using HIC(15) revealed no significant difference between the baseline air bag and the depowered air bag.

Finally we are of the opinion that chest deflection measures are the most appropriate criterion for chest injuries. In NCAP, as in FMVSS 208, chest g's have been used as chest injury criteria since its introduction in 1971. However, recently chest deflection is considered to a better chest injury measure and has been used since the H-III dummy was proposed for FMVSS 208 to reduce concentrated rib deflection by the seat belt. It will also be used for the Euro-frontal impact rule in 1998. In general, it is believed that most life threatening chest injuries are due to mechanical internal organ damage caused by rib deformation. Therefore, using chest deflection for chest injury criteria is thought to be more realistic. In this study, FEM belt with and without a force limiter were

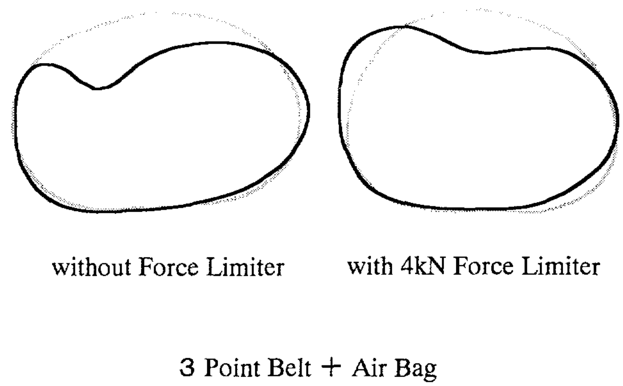


Figure 14. Rib Deformation with and without Force Limiter (Kallieris et al.).

modeled in the MADYMO simulations. Results of similar cadaver tests conducted by Kallieris are shown in Figure 14. They reported that the force limiter prevented partial rib deformation under a severe crash condition. Our simulation of both a depowered air bag and a belt system with a force limiter predicted reduced chest deflection compared with baseline (Figure 8).

CONCLUSION

The results of the MADYMO simulations indicate that depowered air bags reduce AF05 dummy measurements in some moderate frontal impacts.

In the study modeling a 35mph frontal impact, values of HIC and chest g's were slightly higher with depowered air bags than with baseline air bags, but the probability of injuries based on these values were not significantly different. HIC(15) and chest deflection are considered to be biomechanically more appropriate for assessing injury potential than HIC(36) and chest g's, which are widely used in tests such as NCAP. Similar trends were observed using these injury criteria. In specific situation, where depowered air bags result in unacceptable injury measures in 35mph frontal barrier tests, the simulations suggest that the addition of a pretensioner, or a force limiter, or both, may be an appropriate alternative.

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