RESEARCH ON BIOLOGICAL EFFECTS OF IMPACT ACCELERATION WAVE PATTERNS

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A live body receiving an impact is subject to various effects depending on acceleration, duration time, pressure, vibration, and other factors. The human body's reaction is generally judged with the presence or absence of concussion of the brain as the critical threshold. This threshold is defined in SAE J885a by the WSTC (Wayne State Tolerance Curve, L. M. Patrick), a function in wide use. GSI (G. W. Gadd) and HIC (J. Versace) have been proposed as methods of evaluating injury based on the threshold. McElhaney measured head impedance and suggested maximum strain criteria for primates and man.

We have conducted a test to study effects on bodies of impact acceleration for different wave patterns. In the test, the embryos of fertilized hen's eggs were used as (huge) single cells, rats as vertebrates, and monkeys as an anthropoid close to man. The limit of death (LD 50) was used as the standard for evaluation of injury to the bodies. The test was intended to obtain answers to the following questions:

A. Is there any difference in degree of resultant injury between different acceleration wave patterns when inflicted under the same impact conditions (with speed and absorbing distance kept constant)?

B. How does mortality change when acceleration and duration time are changed while keeping impact speed constant?

C. What is the relationship between weight of test subject and tolerance to impact?

1. Effects of impact acceleration wave patterns on the embryos of fertilized hen's eggs

Experimental Method

Fertilized hen's eggs were used for the test because they are unicellular, highly homogeneous, and have little individual variation. The bottoms of the eggs were fixed to a deck with plaster. The eggs, affixed to the deck, were dropped by using a slider guide from heights ranging from 0.5 to 4.0 m to study mortality and abnormality rates.

Impact acceleration wave patterns were controlled by using a lead

Table 1. Criteria of Scale of Injury to Rabbit's Eye and Facial Skin

Injury Scale (IS)	Dgree of Injury	Cornea	Eye Ball	Eye Socket	Facial Skin
-	no injury	no injury	no injury	no injury	no injury
+	Slight injury	Slight surface roughing (I/3 total area) by bag collision.	Subdural hemorrhage	Slight hemorrhage of eye socket.	Slight subcutaneous bleeding, Slight hyperemia.
++	moderate injury	Slight surface roughing (more than I/3 total area) by bag collision	Moderate subadural hemorrhage, hemorrhaging of lacrimal glands, others.	Moderate hemorrhge of eye socket.	Sustained slight subcutaneous bleeding, Slight abrasion.
+++	serious injury	Serious surface roughing (total area) by bag collision.	Serious subdural hemorrage, serious hemorrhaging of lacrimal glands, others.	Serious hemorrhage of eye socket.	Serious subcutaneous bleeding, Abrasion.
++++	serious injury	Cornea laceration, Cornea avulsion.	Eyeball rupture, Eye ground hemorrhage.	Seriou hemorrhage with eye socket fracture	Laceration, Serious subcutaneous bleeding

diaphragm which could be inserted or not was developed. The velocity of air bag inflation could be varied between 5-81 m/sec. We call this the "single tank multivalve air bag system" (Fig. 1).

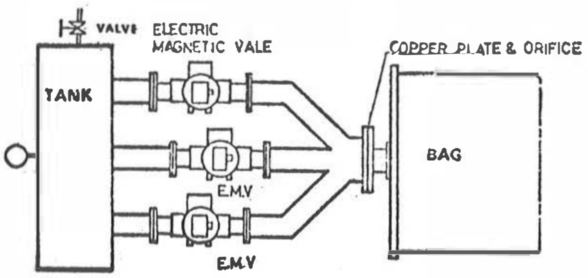

Fig 1. Single Tank Multivalve Air Bag System

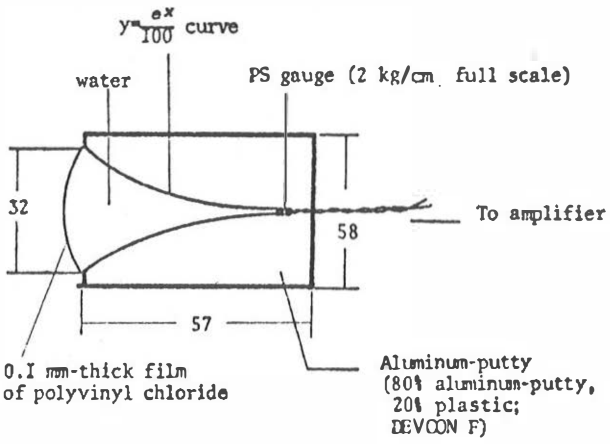

Fig 2. Eye Model (Impulse Measurement Device)

1-3. Test Subjects

The rabbits, oryctolagus cuniculus var. domesticus (Japan white), were anesthetized with a 25 mg/kg intraperitoneal injection of sodium pentobarbital, and their faces were shaved on the impact side. After suturing their eyelids open, they were placed in a wooden box and their whole body was secured in place. The total number of rabbits tested was 37 (9 males, 28 females) and their average weight was 2.97 kg.

1-4. Eye Model

In order to find the impulse on the rabbit's eye, an impulse measurement device called the "eye model"was constructed (Fig. 2). An impression of the contact pattern (replica) was imprinted on the polyvinyl chloride membrane serving as the cornea at the instant of impact.

1-5. Layout

Figs. 3 and 4 show the layout of the test equipment.

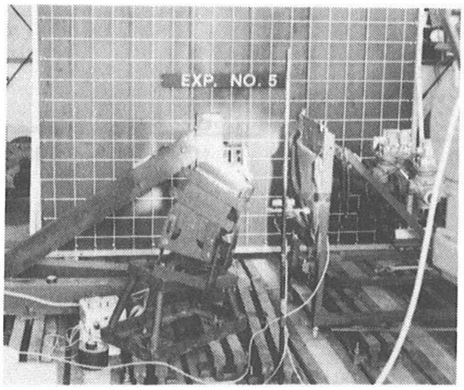

Fig 3. Experimental System

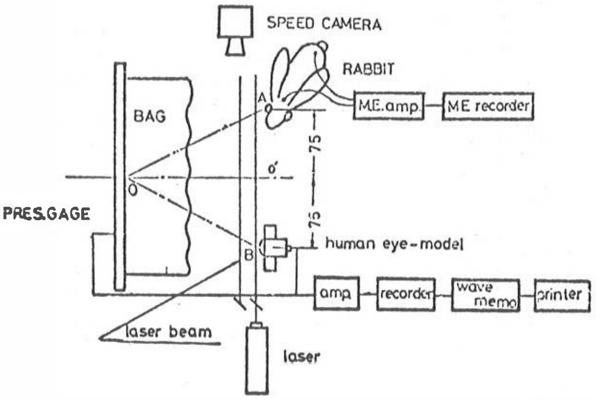

Fig 4. Diagramatic Layout of Experimental Air Bag Inflation System

2. Experimental Results

The results of the measurements of mechanical load are shown in Fig. 5, and the biological injury to the eyes and facial skin of the rabbits is shown in Fig. 6. (Quantitative result tables have been omitted.)

3. Discussion

3-1. Cornea Injury

(1) Major Factor Leading to Cornea Injury

The charts in Fig. 6 show the injury trends differentiated according to whether a copper diaphragm was used or not. At a distance of 200-400 mm the IS readings are roughly the same for both cases, but at distances closer than 200 mm the IS readings go sharply upward for the case where the copper diaphragm is employed.

This differential may be explained as follows.

a) In Fig. 5 it is clear that impulse and bag maximum

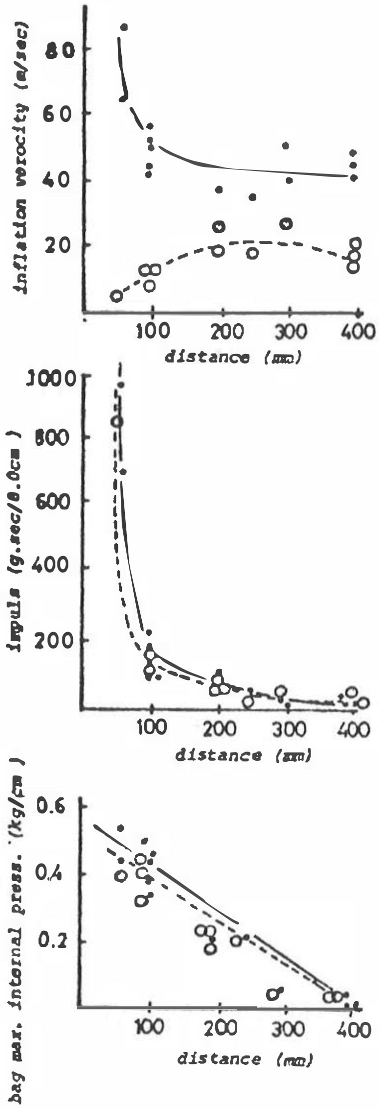

Fig 5. Mechanical Factor Measurements (Inflation Velocity, Impulse, and Bag Maximum Internal Pressure against Distance)

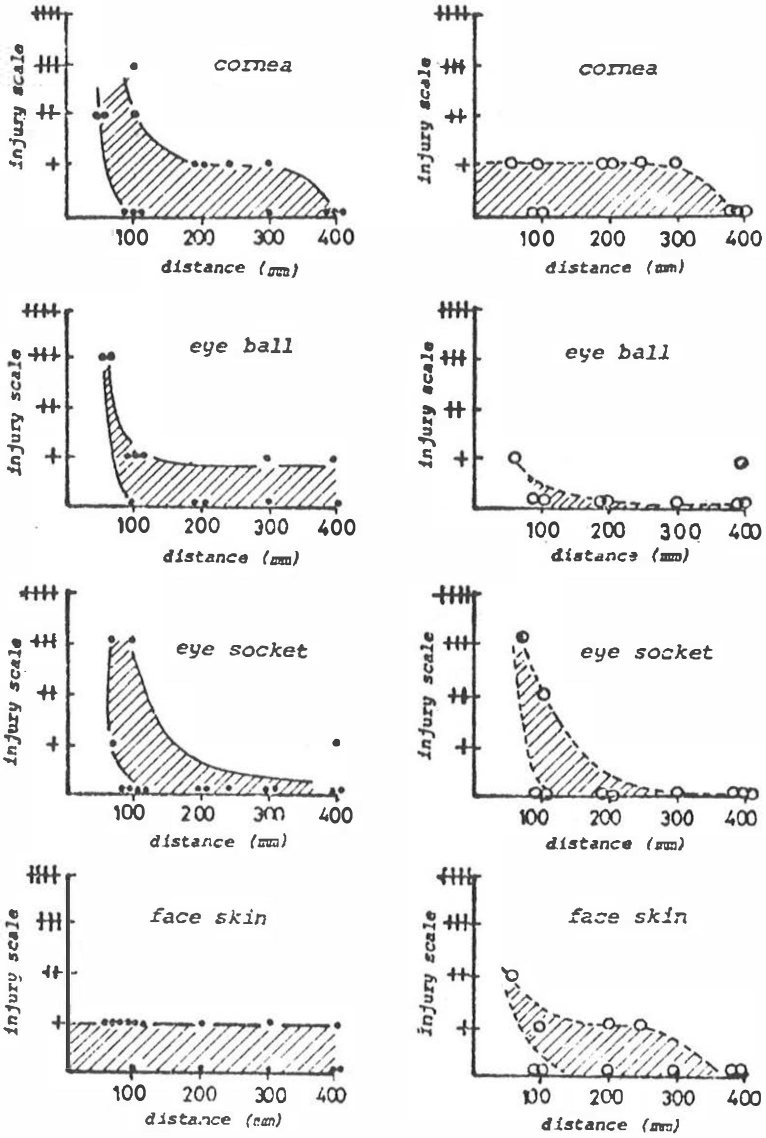

Fig 6. Biological Injury Measurements (Cornea, Eyeball,Eye Socket, and Ficial Skin against Distance)

Note: ● *with copper diaphragm*
○ *without copper diaphragm*

● *with copper diaphragm*
○ *without copper diaphragm*

internal pressure values change in approximately the same pattern whether the diaphragm is present or not. Accordingly, we can safely state that neither factor should be responsible for the differing patterns of cornea injury evident in Fig. 6. b) Inflation velocity, however, does change distinctly in Fig. 5 depending on whether the copper diaphragm is used or not, and the manner of change when the diaphragm is used in the region under 100 mm is an ascending curve that resembles the Fig. 6 cornea injury curve for the same condition. We conclude that the increasing seriousness of cornea injury when a diaphragm is present is due to the velocity of bag inflation.

(2) Change in Inflation Velocity and IS Reading

Over the distance of 200-400 mm the digree of cornea injury is slight (IS +) irrespective of the diaphragm's presence or absence. The inflation velocity graph in Fig. 5, however, indicates over the same distance that velocity is about 50 m/sec when the diaphragm is present and about 20 m/sec when it is not, or a difference of about 30 m/sec. In other words, IS readings remain the same in spite of differing velocities. Let us examine this discrepancy.

Biological phenomena in general are often expressed by a cumulative function known as an ogive or sigmoid curve. In Fig. 7 is illustrated the relationship between bag inflation velocity and the IS readings. Curve AB is the approximate sigmoid curve. Over the 20-50 m/sec range curve AB describes a plateau, indicating that the IS reading is unchanged. We can hence conclude that even though IS readings are equal for both an average velocity of 50 m/sec (diaphragm present) and an average velocity of 20 m/sec (diaphragm absent), no theoretical contradiction exists from the biological phenomenon standpoint.

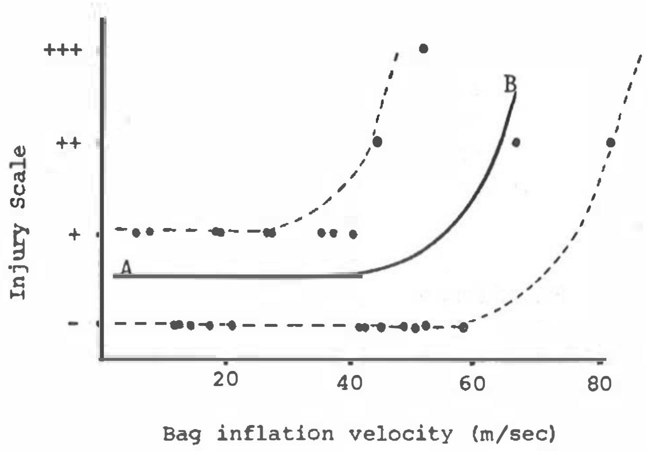

Fig 7. Relation between Cornea Injury and Bag Inflation Velocity

(3) Permissible Safety Thresholds and Recommended Practices

(a) Safety threshold for inflation velocity

From Fig. 7 we can state that a velocity under 41 m/sec is necessary to hold cornea injury within the slight boundary (+ or -). The safety threshold recommended for practice in actual automobile collisions should hence be a relative impact velocity of bag and face less than 41 m/sec.

(b) Safety threshold for impulse

Cornea injury is related to the 3 factors of impulse, bag maximum internal pressure, and inflation velocity at bag impact. In Fig. 8 is shown the relationship between impulse and inflation velocity. The safety threshold and recommended practice for impulse, within the boundaries of velocity 41 m/sec and IS (+), is an impulse of 223 gr·sec/8.0 cm^2. The area within CDE in the figure represents the "greatest safety zone" and the curve ADB is the "forecast injury tolerance curve."

(c) Safety threshold for bag maximum internal pressure

As shown in Fig. 9, bag maximum internal pressure should be 0.44 kg/cm^2. Again CDE encompasses the greatest safety zone and ADB is the forecast injury tolerance curve.

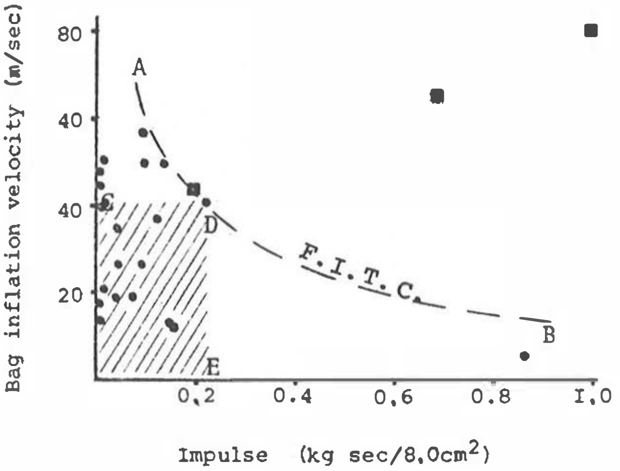

Fig 8. Conea Safety Zone at Impact of Air Bag (Bag Inflation Velocity versus Impulse)

Note: ● *IS - or +*
■ *IS ++ or +++*

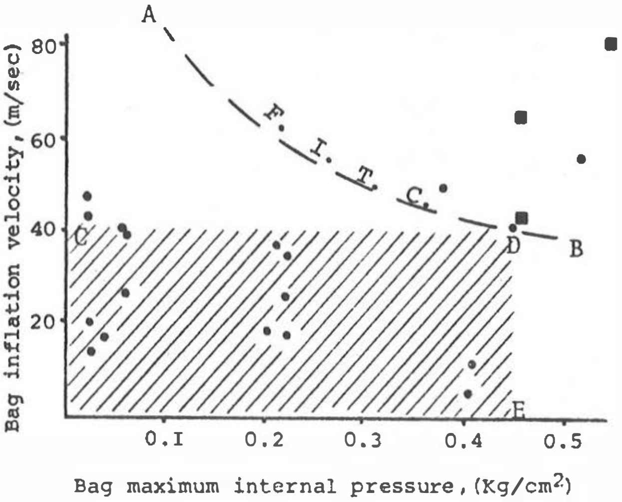

Fig 9. Cornea Safety Zone at Impact of Air Bag (Bag Inflation Velocity versus Bag Maximum Interior Pressure)

Note: ● *IS - or +*
■ *IS ++ or +++*

(4) Cornea Injury Pathological Findings

We shall omit discussion of the correspondence between rabbit's cornea injury and the degree of traces on the model eye polyvinyl chloride menbrane. As a reference, see Figs. 10 and 11.

3-2. Injury to Eyeball, Eye Socket, and Facial Skin

Just as with cornea injury safety thresholds were derived for injury to the eyeball, eye socket, and facial skin with respect to the 3 factors of bag inflation velocity, impulse, and bag maximum internal pressure. The results are presented in Table 2, but detailed discussion will be omitted here.

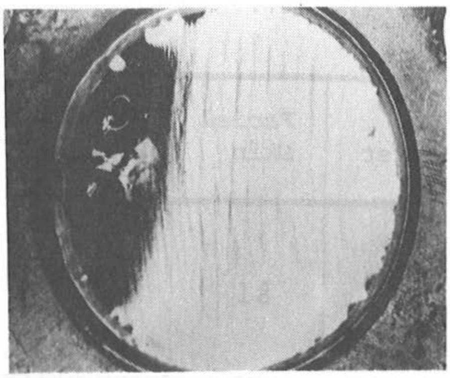

Fig 10. Impression of Bag Fabric on Eye Model PVC Membrane after Impact

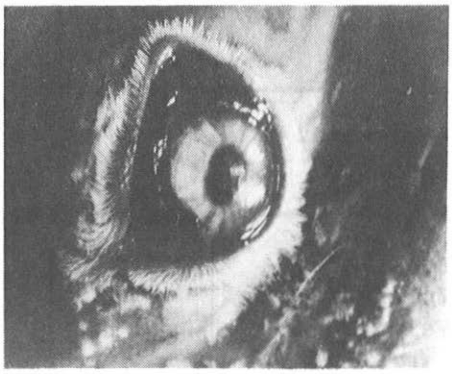

Fig 11. Impression of Bag Fabric on Rabbit's Cornea after Impact

4. Conclusion

An animal experiment using rabbits as the subject was performed to derive the degree of injury to the eye and facial skin on impact with an inflating air bag. Permissible safety thresholds were derived on the basis of the experimental results (Table 2).

It should be noted that if one of the 3 mechanical factors studied here were to be restricted more than the recommended practice, it would be logical to assume that the other factors could be allowed a greater freedom than the safety thresholds we propose. Nevertheless, within the context of our study the set of values given in the right column of Table 2 represents the recommended practice for air bag design proposed to designers as a criterion of safety.

It has been reported that the time required for a human to blink is 28-217 ms.8) Since the inflation time of commercial air bags is 25-35 ms, it is entirely conceivable that eye injury could occur. No model rules have been established to compare the response on impact between humans and rabbits, but it still can be presumed that rabbits are suitable subjects in view of the possible presence of women and children in accidents.

In conclusion. we have demonstrated that the air bag does constitute a source of danger to eye and facial skin, but we do not thereby reason that air bag development and application should be brought to a halt. Rather, our hope is to contribute to the development of safer air bags by

Tabl 2. Proposed Safety thresholds and Recommended Practices for Air Bag Design (Permissible Safety Threshold Values)

Mechanical Factors	*Cornea*	*Eyeball*	*Eye Socket*	*Facial Skin*	*Recommeneded Practice*
Relative Inflation Velocity (m/sec)	4I	57	64	8I	4I
Impulse (Kg sec/8cm²)	223	223	II6	850	II6
Bag Max. Internal Press. (Kg/cm²)	0.44	0.40	0.30	0.39	0.30

I) Permissible safety threshold value mean IS (+ or -).

2) Boldly frame shows major mechanical factor for injury, Normal frame supplementary factors.

demonstrating suitable recommended practices for air bag design.

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