Z. Rechtsmedizin *80*, 171–182 (1977)

Zeitschrift für
**Rechtsmedizin**


*Originalarbeiten – Original Papers*

# Influence of Post Mortem Changes on Experimental Safety Belt Injuries

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**Summary.** Belt protected car occupants involved in head-on collisions do not seem to suffer as severe injuries as unembalmed cadavers subjected to comparable simulated head-on collisions. Therefore it has been questioned if cadavers constitute adequate test specimens for study of thoracic tolerances. This investigation compares injuries in safety belt wearing living and dead pigs which have been subjected to simulated head-on collisions on an acceleration track. Tests were performed on all 20 pigs (10 living and 10 dead). The arterial side of the circulatory system of the dead pigs was infused. The force in the safety belts, the intraaortic pressure, the impact velocity and the deceleration of the sled were recorded. The tests were high speed filmed.
Post mortem examination of the pigs revealed differences in injury severity. Dead pigs more easily suffered rib fractures. Deformation of the rib cage due to stripping of the periosteum and laceration of surrounding tissue occurred mainly in the dead pigs. Laceration of intrathoracic blood vessels was seen in dead pigs while isolated heart lesions were seen only in living animals. The main cause of these differences in tolerance level seems to be post mortem changes of the mechanical properties of the different tissues. The results are valid for pigs but indicate that great care has to be excercised when results obtained from cadaver experiments are evaluated concerning thoracic tolerance.

**Zusammenfassung.** Die Erfahrungen zeigen, daß bei verunglückten gurtgeschützten Fahrzeuginsassen nicht so schwere Verletzungen auftreten, wie sie bei Kollisionsversuchen mit Leichen unter ähnlichen Bedingungen erzielt wurden. Dies ist besonders bezüglich der Thoraxverletzungen der Fall. Es ist deshalb fraglich, ob Leichen geeignete Testobjekte zum Studium der Toleranz des Brustkorbes sind. Es wurden deshalb Aufprallversuche mit angegurteten lebenden und toten Schweinen auf einer Accelerationsbahn durchgeführt. Bei 20 Versuchen war die Aufprallgeschwindigkeit 16 m/sec (20 g) oder 20 m/sec (28 g). Jede Gruppe bestand aus 5 Tieren. Bei den toten Schweinen wurde das arterielle System des Rumpfes während des Versuches infundiert, um damit einen mit dem lebenden Tier vergleichbaren

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This work was supported by the Transport Research Delegation, Sweden

Blutdruck zu erzeugen. Die Kräfte in den 3-Punktgurten, der intraaortale Druck, die Aufprallgeschwindigkeit, und die Beschleunigung des Schlittens wurden registriert. Die Versuche wurden mit der Highspeed-Kamera gefilmt.
Bei der Obduktion der Tiere zeigten sich Unterschiede bezüglich der Schwere der Thoraxverletzungen. Bei den toten Tieren trat eine größere Anzahl Rippenbrüche auf als bei den lebenden Tieren. Außerdem lagen weiter als Folge von Weichteilverletzungen in der Umgebung der Brüche größere Dislokationen der Bruchenden vor. Bei den toten Tieren wurden Verletzungen großer intrathoracaler Gefäße beobachtet, während nur bei lebenden Tieren isolierte Herzverletzungen auftraten. Die Ursache für den Unterschied zwischen der Toleranz des Thorax bei toten und lebenden Tieren dürfte darin liegen, daß die mechanischen Eigenschaften der Weichteile postmortal verändert werden. Die erzielten Ergebnisse gelten für Schweine. Es läßt sich jedoch daraus herleiten, daß die Resultate von mechanischen Toleranzuntersuchungen am Thorax menschlicher Leichen nicht ohne weiteres auf den Lebenden übertragen werden können.

**Key words:** Thoracic tolerance, head-on collisions using pigs – safety belts, head-on collision experiments – traffic medicine, head-on collision experiments, thoracic tolerance in dead and living pigs.

The most frequent impact situations in which unprotected car occupants suffer severe injuries are frontal collisions and roll-over of the cars. To protect occupants from striking interior surfaces of the car and to slow their deceleration, restraint systems such as air bags and safety belts have been introduced. Safety belts are today the most practical mean of protection in the above-mentioned collision situations. The three-point-belt has gained a dominant position. Althoug their protective effects are well documented, research continues on their improvement so that severe body injuries from high speed collisions can be reduced.

Frequently, tests with human cadavers have been performed for this purpose (e.g. Voigt and Lange (1971), Kallieris and Schmidt (1974), Tarriere et al. (1974) and Patrick (1974).

In such investigations unembalmed cadavers were used, which after disappearance of rigor mortis were subjected to simulated head-on collisions on an acceleration track. The results published so far indicate a high frequency of injuries to the thorax, a finding which according to our experiences do not correspond to real situations, when safety belt restrained car occupants have experienced similar collisions. Thus, it must be questioned whether the tolerance of the thorax is the same for living and dead bodies, i.e. if a dead body constitutes an adequate test specimen for investigation of the protective effects of safety belts. The present investigation concerns the protective effects of the three-point-belts against injury to living and dead pigs, which have been subjected to simulated head-on collisions on an acceleration track.

## Material and Methods

### *1. Choice of Test Animal*

Pigs were chosen as a test animal in order to investigate the injuries inflicted to dead and living tissue in similar traumatic situations. The pigs were subjected to head-on collisions where acceleration and velocity levels were comparable to real life car accidents. According to Douglas (1972) the pig is suitable as a test substitute for man in biomechanical research. The geometrical dimension of the torsos are similar and the configuration and relative weight of the internal organs are comparable. However, the pig has 15–16 pairs of ribs while man has 12. Furthermore, the pig lacks clavicles. In a horizontal section the thorax of man is flattened in the sagittal direction while the thorax of the pig is more flattened from the sides (Fig. 1). Another important difference is that the heart is situated more cranially relative to the liver in the pig and the thoracic part of the inferior vena cava is much longer than in man. The anatomical architecture of the individual ribs is different. The cartilaginous part has a somewhat softer consistency and meets the sternum in a steeper angle in the pig than in man. It is flatter on cross section. The sternum of the pig consists of different bone segments which are connected to each other by cartilage and connective tissue and correspond to the rib pairs. On the anteroir side of the sternum there is a strong longitudinal ligament (referred to here as the presternal ligament) consisting of the radiating sternocostal ligaments.

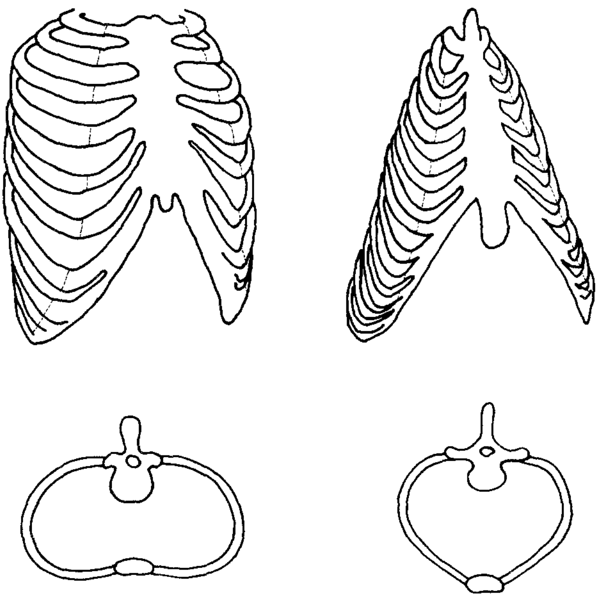

Fig. 1. Schematic views and sections of the rib cages of man (left) and pig (right)

These anatomical differences between pig and man indicate that the results obtained in dynamic testing of the pig thorax cannot be transferred to man. Different injury patterns can be expected under the same impact conditions. However, no importance can be attached to these geometrical differences when identical traumatic impacts to living and dead tissue are studied. The mechanical behavior of the individual tissues can be assumed to be similar for man and pig, and the question raised is whether living and dead tissues have the same mechanical properties.

Whenever thoracic injuries are concerned some primate should offer the best substitute for man. In the present investigation pigs were chosen because they are readily available and comparatively inexpensive. Common domestic pigs with a weight of about 30 kg were used. Young pigs were chosen because they are easy to handle and when anesthetized they do not suffer blood pressure fall and respiratory arrest as easily as old pigs.

*2. Acceleration Track*

The tests were carried out using an impact testing track designed and built at the Division of Solid Mechanics, Lund Institute of Technology (Wihlborg, 1975). A sled especially constructed for this testing was accelerated to the desired velocity along a runway of 30 m. The deceleration was kept at a constant level during the collision phase. This was achieved by drawing a steel band around a pulley. The work of the plastic deformation needed to draw a unit lenght of the band around the pulley was constant and thus also the force executing the decelerative work. The lower part of the sled contains the steel band. A beam at the deceleration side catches the middle of the band which is drawn around the pulleys. The upper part of the sled consists of a framework with a seat for the pig and attachments for the safety belts. Cf. Figure 2 for complete set-up.

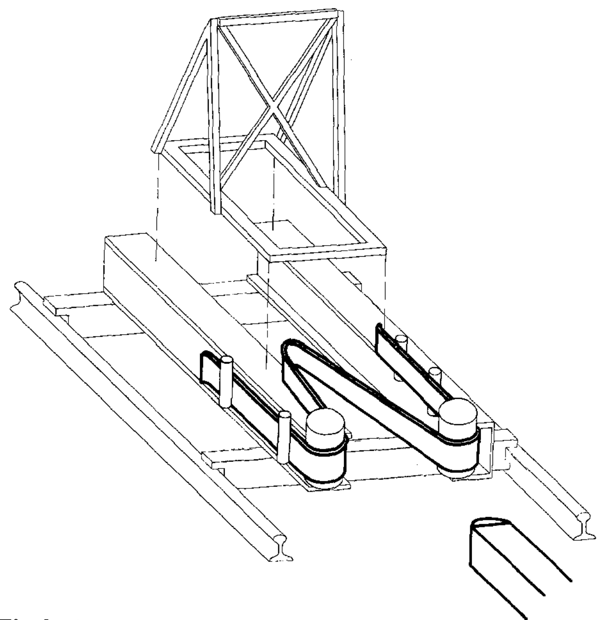

Fig. 2. Arrangement for deceleration of the sled

*3. Seat Belts*

Standard seat belts used in Sweden have a width of 50 mm. In the present tests seat belts with a width of 35 mm were used as a consequence of scaling in order to take the lower weight of the pigs into consideration. The stress-strain properties of the belts used were chosen such that a scaletrue elongation of the belts were obtained. In the experiments three-point-belts were used with separate shoulder and lap parts.

*4. Test Performance*

Twenty impact tests with living and dead pigs have been performed at two different impact velocities, 20 m/sec and 16 m/sec. The average decelerations at the two impact velocities were 28 and 20 g respectively. Figure 3 shows a typical deceleration profile of the sled as a function of the time. The average deceleration is defined as the average value of the plateau phase.

In Figure 4 the final velocity of the sled is indicated versus the average deceleration. The values for the high and low velocity tests are well grouped except for one experiment in the low velocity series.

The living test pigs were anesthetized with Ketalar®, a short acting anesthetic of a non-barbiturate type. By intravenous administration the depth of the anesthesia could be controlled so that muscle tone was maintained.

For the experiments with the pigs, the animals were killed with an overdose of pentobarbital intravenously. The cadavers were kept at a temprature of +4° C for about 2–3 days so that rigor mortis had disappeared. Thus the pig cadavers were used after a corresponding length of time after death as the human cadavers in the previosly mentioned experiments.

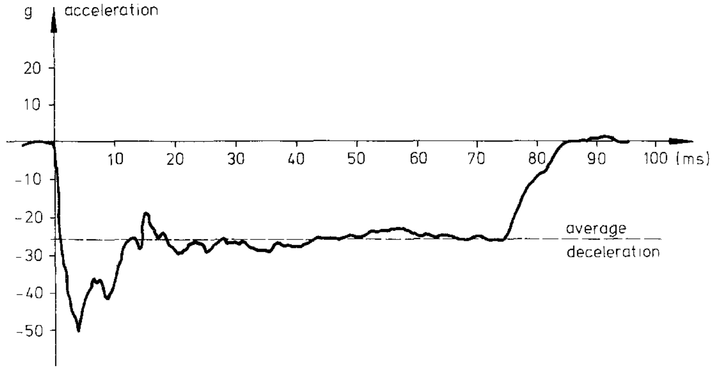


**Fig. 3.** Typical deceleration profile

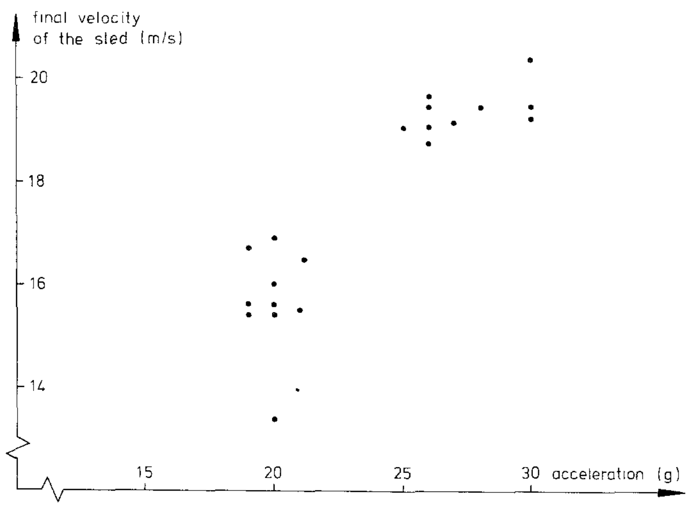


**Fig. 4.** Deceleration of the sled vs. the final veloctiy

A catheter-tip pressure transducer was introduced via the left carotid artery into the ascending part of the aorta till just above the aortic valve.

The test pig was placed in a sitting position on the acceleration sled and the seat belts were attached. Care was taken that the shoulder belt crossed the middle of the sternum. In living pigs respiration and circulation was monitored continously before and after impact. In cases of respiratory arrest after impact artificial respiration was given so that life could be maintained to allow hemorrhages to develop. Thirty minutes after impact the pig was killed with an overdose of pentobarbital intravenously. Autopsy of the pig was performed about 1 day after the impact. In order to create as nearly identical test conditions as possible between the groups of living and dead pigs, the arterial side of the circulation was repressurized by physiological saline solution through the right carotid artery until the intraaortic pressure approached blood pressure for living pigs. The venous side of the system was not repressurized because of the fact that earlier experimental investigations have shown that the lungs become filled by the saline, making their compliance unsuitable for such tests. It is important to maintain the aortic pressure during the collision. Coermann et al. (1972), who were the first to perform cadaver tests with an artificial intraaortic pressure, stopped the infusion just before the impact test which resulted in a decrease of the intraaortic pressure until te moment of collision. In the present tests the intraaortic pressure

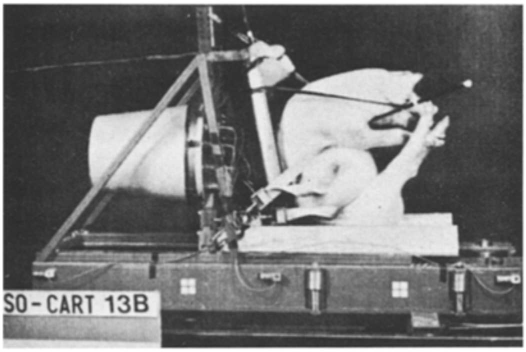



**Fig. 5.** Typical behaviour of the pig during impact

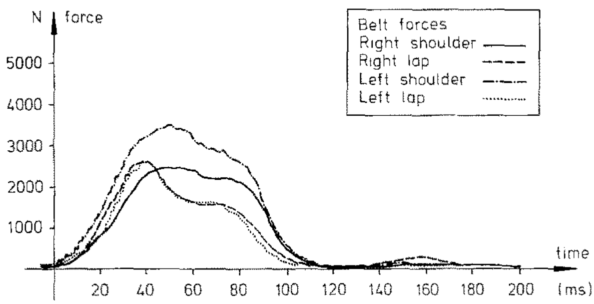



**Fig. 6.** Seat belt force recordings from a low velocity experiment

**Table 1.** Belt forces average ± S.D. for the two impact velocities

| Impact velocity | 20 m/sec. | 16 m/sec. |
|---|---|---|
| Left shoulder belt | 4250 ± 350 N | 3400 ± 250 N |
| Right shoulder belt | 4550 ± 300 N | 2700 ± 250 N |
| Left lap belt | 3300 ± 500 N | 2350 ± 400 N |
| Right lap belt | 3600 ± 350 N | 2500 ± 400 N |
| Average difference in shoulder belt forces | 500 ± 400 N | 750 ± 150 N |
| Average difference in lap belt force | 75 ± 150 N | 100 ± 200 N |

was maintained by continuous infusion of saline solution during the entire test by using special equipment attached to the sled. The impact test was carried out when an aortic pressure of 70–80 mm HG could be read from the pressure transducer. Infusion was stopped after impact. In order to reduce the infused volume the large arteries and veins to the extremities were ligated. Ligation of the jugular veins and the carotid arteries was performed during the introduction of the pressure transducer and the attachment of the infusion equipment. The amount of the saline solution used in each test animal was approximately 0.5–1 liter.

## Results

### *1. Movement Patterns of the Pigs*

During impact, the movements of the pigs were recorded by means of two high speed cameras. Before the test, the shoulder belt was checked to pass over the middle of the sternum. During the acceleration of the sled it is possible that the initial position of the pig may be altered. In order to reach a final velocity of 20 m/sec an acceleration of 1 g was needed because of the limited length of the acceleration track. Furthermore, the length of the pigs varied (98.4 ± 3.4 cm) so that completely identical seat belt geometries were difficult to achieve. Thus, the braking forces of the belts have been acting at somewhat different levels of the thorax of the pig. According to the autopsy findings, fracture of the sternum was found between the insertion of the second and the third pairs of ribs or between the third and fourth pair of ribs in most of the cases. In these cases analysis of the high speed films showed that the pigs were decelerated with a maintained position of the body (see Fig. 5). Slight left rotation could occur due to the attachment of the shoulder belt: left top to right bottom. In some few cases there was a fracture of the sternum between the insertion of the first and second pairs of ribs. In these cases there was no or a very slight rotation of the torso, but there was a tendency to submarine. There was no difference in the pattern of movements between living and dead pigs at high or low impact velocities.

### *2. Seat Belt Force Recordings*

The pigs used had an average weight of 29.8 ± 1.8 kg. The belt forces were recorded at the attachment points in the direction of the belts. The average belt forces for the two velocity groups are given in Table 1. Figure 6 gives a typical force recording. The average deceleration was 19 g, and the corresponding duration 80 msec. The peak value of the lap belt force was reached after 40 msec and decreased to a plateau phase corresponding to the force that should be obtained in the belts if the deceleration had had a very long duration. The shoulder belt forces reached a maximal value after about 50 msec. Here, too, a tendency of a plateau phase was seen. The sled came to a complete standstill after about 80 msec and the belts were rapidly unloaded.

Usually, the forces in the shoulder belts were 1000 N higher than in the lap belts. However, in cases with submarining, the lap belt forces could exceed those of the shoulder belt.

The forces recorded in the experiments with living and dead pigs did not differ significantly in the high and low velocity groups.

### *3. Pressure Recordings*

The average values for the maximal aortic pressures are apparent from Table 2. Experiments with deviating patterns of movement are not included.

Pressure variations in the aorta reflected the forces in the belts especially at the low velocity. In several test pressure peaks were obtained which had no counterpart in the force recordings. Sudden changes in the thoracic volume in connection to the rib and sternum fractures explain these peaks.

The stability of the thoracic cage has great importance regarding production of thoracic pressure. The recorded pressures in the living and the dead pigs in the low

**Table 2.** Average value ± S.D. of the maximal intraaortic pressure. In some cases with the dead pigs at the high velocity the recording equipment was overloaded

| Impact velocity | 20 m/sec. | 16 m/sec. |
|---|---|---|
| Living pigs | 670 ± 110 mm Hg | 600 ± 60 mm Hg |
| Dead pigs | 1150 ± 170 mm Hg | 760 ± 260 mm Hg |

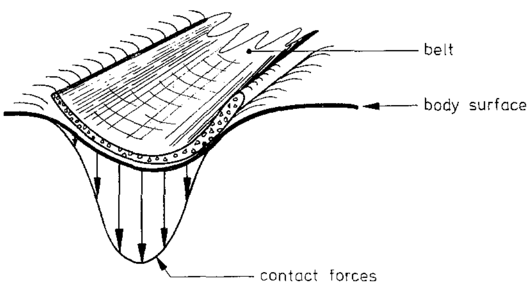


**Fig. 7.** Effective contact area between belt and body

**Table 3.** Number of rib fractures/number of rib fracture dislocations

| High velocity, 20 m/sec. | | Low velocity, 16 m/sec. | |
|---|---|---|---|
| Living | Dead | Living | Dead |
| 16/0 | 19/15 | 13/0 | 14/6 |
| 16/0 | 16/9 | 8/0 | 12/4 |
| 15/0 | 16/7 | 5/0 | 12/0 |
| 14/2 | 9/4 | 4/0 | 7/5 |

velocity group, whereas there was a marked difference in the high velocity group. In one test the shoulder belt had a low position and there was no fracture of the sternum. The peak pressure of 400 mm Hg obtained in this case is very low compared to the other values which averaged 1150 mm Hg.

*4. Injuries to the Pigs*

Skin abrasions at the front side of the chest and the abdominal wall generally indicated the contact area with the restraining belts. The width of the abrasions was smaller than the width of the belts. From the high speed film it was apparent that the belts were buckled so that the force interaction was restricted to the central part of the belts (see Fig. 7).

The autopsies included thorough investigation of the internal soft tissue injuries, injuries to the brain and fractures of the thoracic cage, spine and skull.

A summary of the internal soft tissue injuries obtained for the different velocity groups is given in Table 3. Table 4 details the frequency of the rib fractures. Based on the recordings (high speed film, transducer measurements), some pigs were excluded from further analysis. Of the remaining 16 pigs all showed fracture fo the sternum. Complete disruption of the presternal ligament however, was seen only in the high velocity group with dead pigs (3 cases), and in none of the living animals. No injuries to the spine, skull or brain were found. Laceration of subcutaneous fat and muscular tissue due to the belt action during impact were generally found. Three pigs belonging to the high velocity group suffered fatal injuries to the superior vena cava and/or the wall of the right atrium of the heart (Cf. Table 3) and died within ten minuntes.

**Discussion**

Ten high and ten low velocity tests were performed with five living and five dead pigs in each group. As the experimental test conditions should be as nearly identical at each velocity, four tests were excluded (submarining etc.). In the discussion below each group contains four pigs.

It must be emphasized that the pigs tested constitute a homogenous material concerning age, weight and length. This is generally not the case when comparison is made between tested human cadavers and real traffic causalties, the latter usually belonging to a younger age group.

*1. Low Velocity* (16 m/sec, 20 g):

A larger number of rib fractures was obtained in the dead pigs than in the living pigs. The average numer of rib fractures was 12 and 7.5 respectively. In the dead animals the fragments of the fractured ribs were dislocated from each other due to laceration and stripping of the periosteum surrounding the fractures (Fig. 8). The cause of these more severe injuries in the dead pigs may be post mortem decomposition of the soft tissue and consequently changes of the mechanical properties. Rib fracture ends which have been stripped free of soft tissue may more easily cause laceration of adjacent internal organs, primarily the lungs. This did occur in two dead pigs: the rib fragments had been impressed into the lungs and thereby caused channel shaped lacerations. The complete lack of stability of the fractured areas caused deformation and dislocation of the internal organs in the reduced space between the spine and the frontal wall of the chest. This mechanism allows explanation of the injuries to the superior vena cava (in one dead pig) and to the right atrium of the heart (in one dead pig).

*2. High velocity* (20 m/sec, 28 g)

There were extensive rib fractures both in the living and the dead pigs. However, in the dead pigs the soft tissue injuries around the fractures, stripping of the periosteum and laceration of surrounding muscles and pleura were more pronounced than in the living. The soft tissue injuries around the fractures produced a significant instability of the chest in the dead pigs. The fracture ends of the ribs, and especially of the sternum, could be markedly dislocated. Rupture of the superior vena cava was seen in all of the dead animals, while only in one of the living. Rupture of the truncus brachiocephalicus was seen in all the dead pigs but in none of the living. These injuries are to be regarded as a consequence of the pronounced compression and deformation of the intrathoracic tissues because of the thoracic injuries. Isolated heart injuries were not seen in the dead pigs which may be explained by the fact

**Fig. 8.** Stripping of the periosteum from the ribs. A common finding in the dead pigs

**Table 4.** Intrathoracical and intraabdominal injuries

| High velocity, 20 m/sec. 4 living pigs | 4 dead pigs |
|---|---|
| 3 lung hermorrhages | 3 lung lacerations |
| 1 lung laceration | 2 rupt. sup. v. cava |
| 1 rupt. sup. v. cava – right atrium | 1 rupt. sup. v. caba – right auricle |
| 1 rupt. sup. v. cava – right auricle | 1 rupt. sup. v. cava – right atrium |
| 1 rupt. right atrium – auricle | 4 rupt. pericardium |
| 3 rupt. pericardium | 3 disruption brachiocephalic truncus |
| 2 rupt. small intestine | 2 liver lacerations |
| 1 rupt. right kidney | |
| **Low velocity, 16 m/sec. 4 living pigs** | **4 dead pigs** |
| 2 lung hemorrhages | 2 lung lacerations |
| | 1 rupt. right atrium |
| | 1 rupt. sup. v. cava |

that the venous side of the circulation was not repressurized, and thereby no intracardial pressure of the right heart.

The more extensive deformation of the thoracic cage in the dead pigs may explain that the recorded pressure in the aorta can reach higher values than in the living pigs. In none of the cases were there aortic lesions of any kind although the intraaortic pressure exceeded the tolerance level for the aorta in man given by Coermann et al. (1972).

## Significane of Post Mortem Changes

The experiments performed show that there are dissimilarities in the injury patterns and tolerance levels between living and dead pigs. It is, however, not possible to quantitatively evaluate the tolerance levels for the different injuries. The main dissimilarity ist the greater thoracic deformation in the dead pigs. Different explanations can be offered.

1. Loss of muscular tone in the dead animals may change mechanical response. Absence of tone in the comparatively small intercostal muscles is however not likely to significantly decrease the thoracic stiffness, since bending and twisting of ribs constitute the main part of the rib cage compliance.

2. It has been put forward, e.g. in the discussions of the International Ad Hoc Committee Meeting on „Human Subjects for Biomechanical Research", that the lung volume of a human test cadaver should be restored in order to obtain appropriate thoracic and abdominal stiffnesses. Practical experience and recommendations are so far limited, and such a scheme has not been applied in our experiments.

3. Autolysis begins a short time after death if the tissues are not embalmed. A common finding in the group of the dead pigs was laceration and stripping of the periosteum around the rib fractures (Cf. Fig. 8). Such stripping was never found in the group of living pigs. It is reasonable to assume that this stripping is a consequence of a decreased strength in the connection between a rib and its periosteum, and that this decreased strength is due to autolytic changes. Obviously, a fractured rib with intact periosteum retains some of its load carrying capability, since the fracture ends are maintained in their original position. On the other hand, if the fracture ends are stripped free from their surrounding periosteum, they are easily dislocated relative to one another and the load will be transferred to neighbouring ribs with increased hazard for additional fractures as a consequence. Other factors (body temperature, adequate repressurization of the circulatory system etc.) might of course also contribute to some extent.

In the low velocity group the numbers of ribs fractured differ markedly between living and dead pigs (Cf. Tab. 2). The causes of this difference seem to be autolytic changes and the eventual cushioning effect of air-filled lungs, if any, but their individual contributions cannot be separated. In the high velocity group the numbers of rib fractures are comparable. Obviously the protective effects of air-filled lungs and intact periosteum are less apparent when the trauma to the thorax increases in severity. It seems that the tolerance levels are definitely passed for both living and dead pigs at the high velocity.

At both velocities severe laceration of internal organs was most pronounced in the dead pigs (Cf. Tab. 3). These injuries are caused by the more extensive thoracic deformation and the impression of the sharp fracture ends of the ribs and the sternum into the various organs. Stripping of the periosteum due to autolytic changes seems to be the natural explanation, since this mechanism accounts for decreased stability of the rib cage and formation of free, sharp fracture ends. The decreased tolerance of the presternal ligament also seems to be due to autolytic changes.

The results of the experiments thus reveal that the tolerance levels for thoracic injuries in dead and living pigs are different. Nor do the injury patterns correspond. The results obtained are valid for pigs. Even if animal tolerance levels and injury patterns cannot be applied to man, post mortem changes must play the same role in man as in pig. Consequently different tolerance levels and injury patterns must also be expected in living and dead human beings. Therefore, great care should be exercized when results obtained from cadaver experiments are evalutated concerning the tolerance of the thorax and the intrathoracic organs.

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*Received February 4, 1977*