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Preparation, Cardiopulmonary Pressurization and Rigor Mortis in Cadaver Testing

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The Institute for Legal Medicine of the University of Heidelberg performed crash tests with unembalmed human cadavers since 1973.

In November 1993, the using of cadavers for traumatomechanical investigation has been criticised in the public. The investigations were especially rejected by representatives of the churches.

The Heidelberg ethics commission came to the conclusion that in investigations with cadavers a greater protection for life and health of road users can be expected; the commission recommends the crash tests with cadavers.

The Ministry for Science and Research of the State Baden-Württemberg has no reservations about continuing the planned biomechanical investigations at the Institute for Legal Medicine provided that the decisions of the ethics commission are met.

At the University of Heidelberg we use test subjects of sudden death cases e.g. acute poisoning, heart failure, suffocation etc., cases which have experienced a reanimation are excluded. The time between death and test amounts 1 - 4 days; prior to the test, the cadavers have been stored at a temperature of 4°C. During this time and these storage conditions no external putreactive symptoms can be recognized.

The body temperature of the subjects ranges from 10°C to 20° C during the test. The age of the subjects amounts from 20 to 65 years (mean 40 years), the height from 160 to 190 cm and the weight from 60 to 90 kg.

After the reading of the present information on the cadaver follows an external inspection with photographic documentation and additional palpation regarding possible skeletal injuries.

Afterwards, standard x-rays of head and thorax are made in order to document also the internal condition of the head and the chest.

After the x-ray documentation anthropometric measurements are made. Along with the age, weight, sex, height this information includes 37 anthropometric parameters according to the NHTSA Data Tape Reference Guide (Contract No. DT NH22-84-C-07368). In order to make these measurements possible in the extremities the still present rigor mortis has to be eased mechanically. By fully marked rigor mortis, lacerations of the dorsal muscles of the thighs were observed during this operation.

Thorax Instrumentation

By using the 12-accelerometer-array (Robbins et al. 1976, Eppinger et al. 1978) a preparation of the skin, fat and muscles at the level of the 4th and 8th rib left and right is needed, afterwards the fixation of the mounts by steel wire at the ribs is made (Fig. 1), further the fixation of the accelerometers by screws is performed (Fig. 2), followed by an imitation of the fat and muscles and finally the skin is restored, in the original situation (Fig. 3). The mounts for the accelerometers at the sternum are screwed on the bone (Fig. 4, Fig. 5), furthermore the 3-axial-accelerometers at Th1 and Th12 at the vertebral bodies.

A tracheotomy is also performed and a tube is inserted to allow pressurization of the pulmonary system to provide a near physiological impedance state of the thorax (Kallieris et al., 1981). The pressure transducer was also inserted at this time to monitor pulmonary pressure (Fig. 6). Before the crash a pressure of about 6kPa in the lung was given.

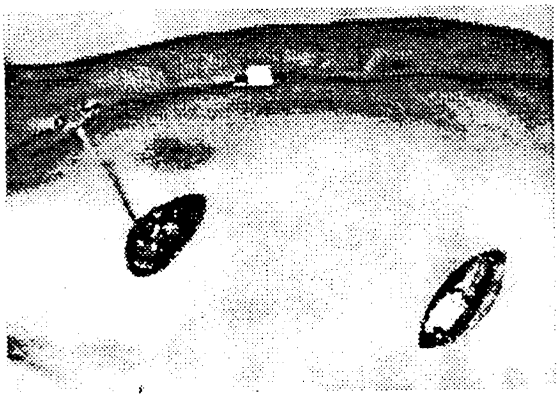


Fig. 1: Fixation of the accelerometer mounts at the 4th and 8th rib right

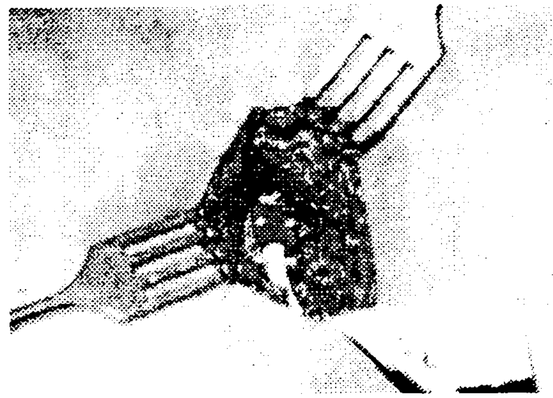


Fig. 2: Installation of the rib accelerometer

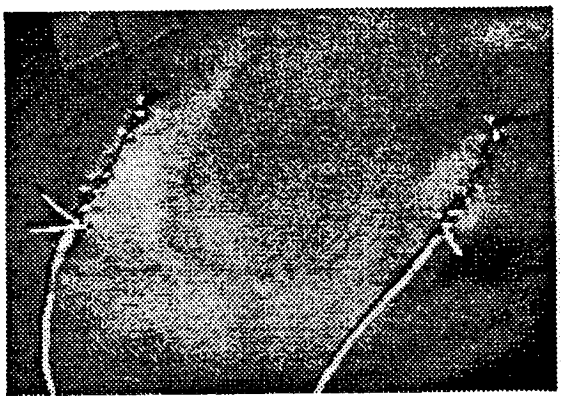


Fig. 3: Prepared skin after the installation of the rib accelerometers

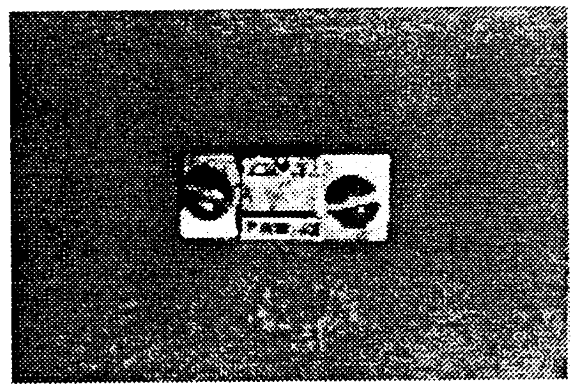


Fig. 4: Fixation of the accelerometer mount at the sternum

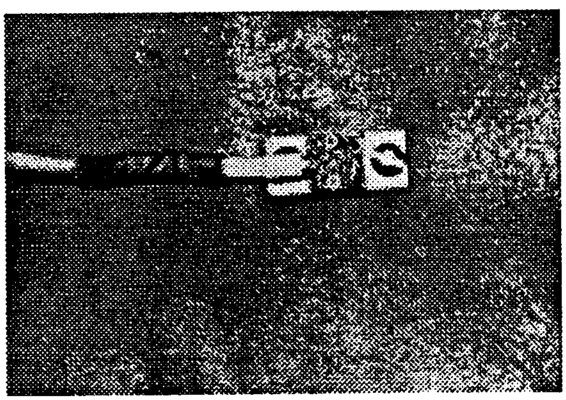


Fig. 5: Installation of the sternum accelerometer

Fig. 6: Thorax with pressure transducer to monitor pulmonary pressure

After dressing and covering the head of the cadaver he is transported to the test facilities. In sitting position, the chest bands are installed at the level of the 4th and 8th rib (Fig. 7, Eppinger, 1989). The initial contour of the subject is checked against 13 separate actual physical dimensions by measuring with an anthropometer (Fig. 8, Fig. 9, Kallieris et al., 1994).

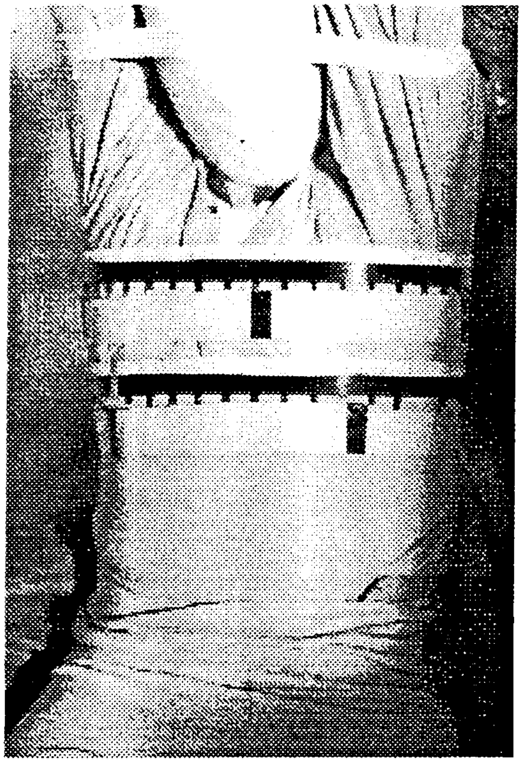


Fig. 7: Installed chest bands at the level of the 4th and 8th rib

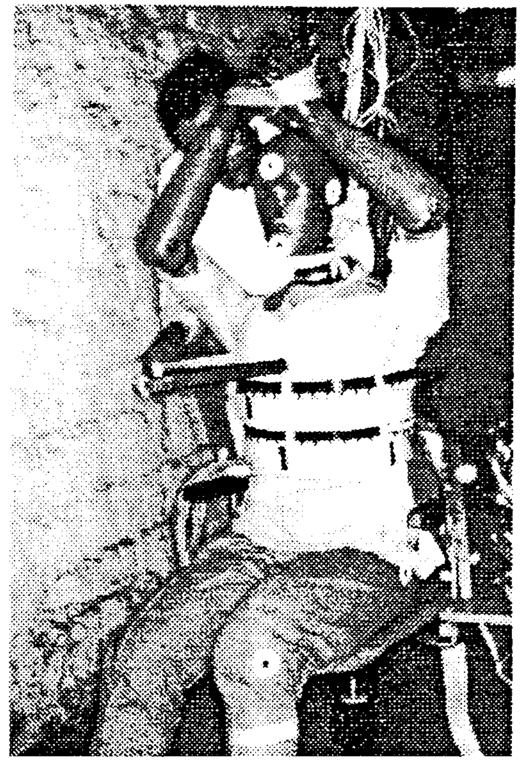


Fig. 8: Measuring of physical dimensions with an anthropometer to check the initial chest contours

After the test follows again a x-ray investigation of the thorax.

Post test protocol provides for a full and complete autopsy to document the trauma sustained as result of the impact. A detailed examination of the entire spinal column is performed.

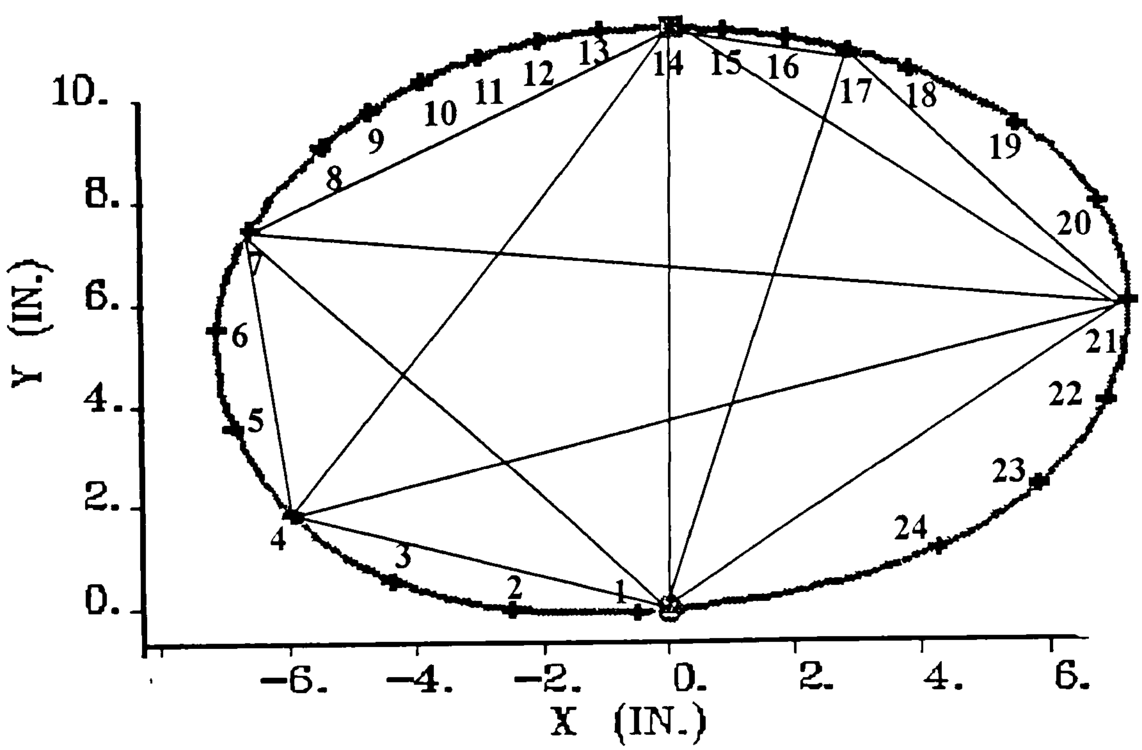
On behalf of it the spinal column with the base of the skull was extracted from the body and in a frozen condition sawed to pieces in the mean x-z plain and the two x-z parallel planes through the lateral joints and was then evaluated (Fig. 10, Mattern, 1980).

The muscle tone of the living human is comparable with the rigor mortis of the cadaver. A fully marked rigor mortis corresponds to a very strong muscular tension in a living person. In order to reach the same conditions for the simulation of muscle tone in living people a comparison of neck responses between volunteers and cadaver testing was conducted, 100 ml 10% solution of formaldehyde was injected in the rear and side muscles of the neck of the test subject. The time between the injection and the test amounted about 20 hours. By that it was attained that the contraction condition of the muscular system in the neck area was controlled in all tests. Fluctuations as they usually occur in the condition of rigor mortis, were reduced because of this measure (Wismans et al., 1987).

This means, that in the cases with a relaxed rigor mortis a contraction condition has been established which can be compared with a medium strong muscular tension in a living person. In a fully marked rigor mortis an additional contraction by means of formaldehyde injection could

Fig. 9: Physical dimensions and initial thorax contour by using the chestband

				Man.	Calc.	Man.	Calc.
Active Band Length (Circumf.)				in cm : 104.0		in inch : 40.94	
L1	Spine	-	21	in cm : 22.3	23.4	in inch : 8.78	9.20
L2	21	-	4	in cm : 31.2	34.7	in inch : 12.28	13.7
L3	21	-	7	in cm : 33.0	35.4	in inch : 12.99	13.9
L4	21	-	Sternum	in cm : 26.0	27.1	in inch : 10.24	10.7
L5	21	-	17	in cm : 15.7	16.7	in inch : 6.18	6.56
L6	17	-	Spine	in cm : 27.3	28.5	in inch : 10.75	11.2
L7	7	-	Spine	in cm : 24.5	25.2	in inch : 9.65	9.91
L8	4	-	Spine	in cm : 14.0	15.5	in inch : 5.50	6.09
L9	4	-	Sternum	in cm : 26.1	27.5	in inch : 10.28	10.8
L10	4	-	7	in cm : 13.3	14.5	in inch : 5.24	5.71
L11	Spine	-	Sternum	in cm : 27.5	28.8	in inch : 10.38	11.3
L12	17	-	Sternum	in cm : 7.50	10.0	in inch : 2.95	3.92
L13	7	-	Sternum	in cm : 18.8	17.8	in inch : 7.40	7.01
	Sternum	-	Ga: 14	in cm : 0.3		in inch : 0.12	
	Sternum	-	Ga: 15	in cm : 2.2		in inch : 0.86	
	Spine	-	Ga: 1	in cm : 1.5		in inch : 0.51	
	Spine	-	Ga: 24	in cm : 10.0		in inch : 3.91	



not be obtained. A significant difference of the T1 vertical displacement between the cadaver and the volunteer test was found. Wether the absence of muscle activity in the cadaver is the explanation for this difference, is unanswered. The injury pattern of the cervical spine was the well known in belt protected occupants in the situation of the frontal collision (Fig. 11, Wismans et al., 1987)

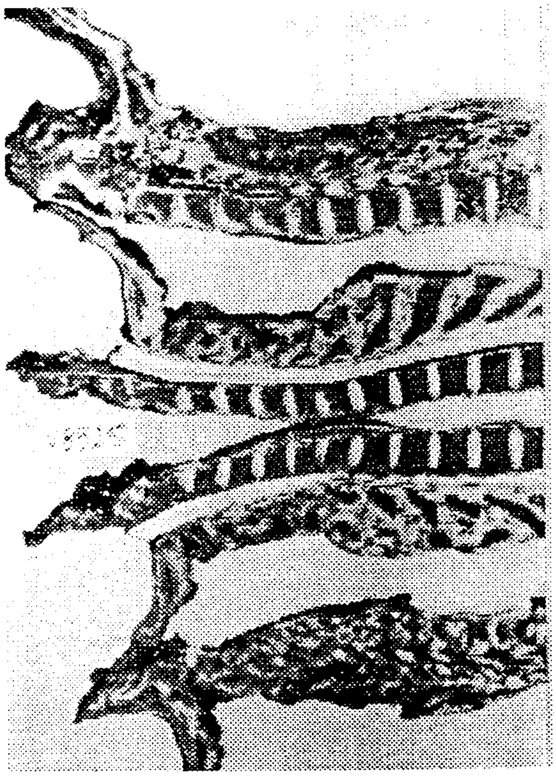


Fig. 10: Spinal column sawed in x-z parallel planes

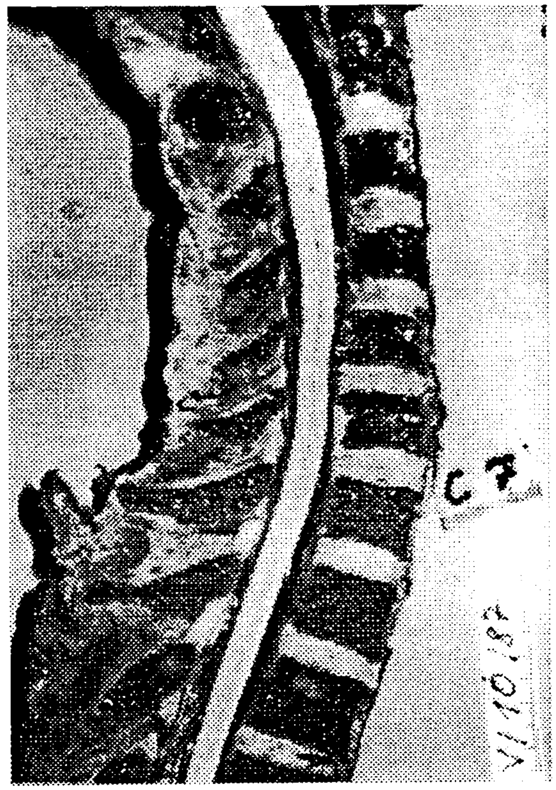


Fig. 11: Middle sagittal cut of the spine with laceration of the lig. flavum TH2/Th3

According to our traumatomechanical experience with cadaver testing, the degree of rigor mortis did not influence the kinematics, the response or the injury severity.

The idea of the repressurization is well understandable, however the question is, whether it is really more realistic and worth the effort.

In our group, no cardiovascular pressurization and no brain vascular pressurization was performed.

As typical injuries for frontal collisions we found sternum fractures (Fig. 12) and rib fractures, in most cases infractions occurred, more rarely were dislocations with transfixing of the lungs and lung contusions. Liver ruptures were more often observed when only using a shoulder belt or 3-point belt and a higher impact severity (Fig. 13, liver rupture with separation of the lig. tereshepatis caused through the compression between the belt and the vertebral column, Kallieris et al., 1994).

In side collisions the liver rupture was the typical injury for 50 km/h car to car right side impacts (Fig. 14). In left side car to car collisions also spleen, additionally liver ruptures were observed in a higher impact severity, furthermore also kidney contusions. The figures 15 and 16 show multiple spleen ruptures and liver rupture caused in a 32 km/h rigid wall left side impact (Kallieris and Mattern, 1986).

Fig. 12: Sternum fracture

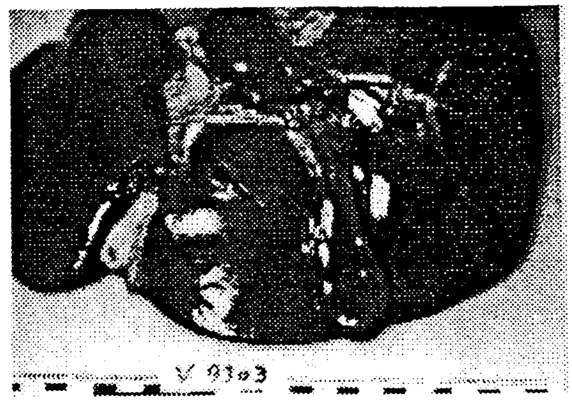


Fig. 13: Liver rupture caused in frontal collision by using 3-point belt

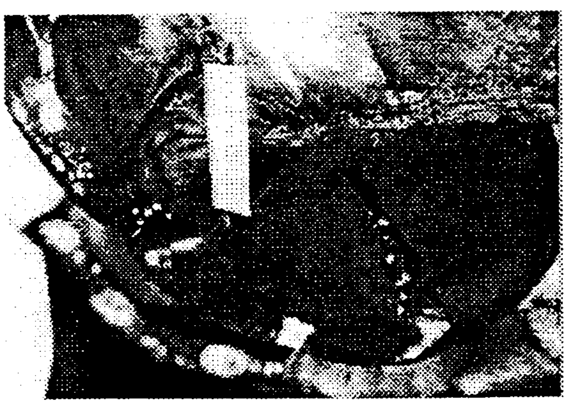


Fig. 14: Liver rupture caused in a car to car right side impact

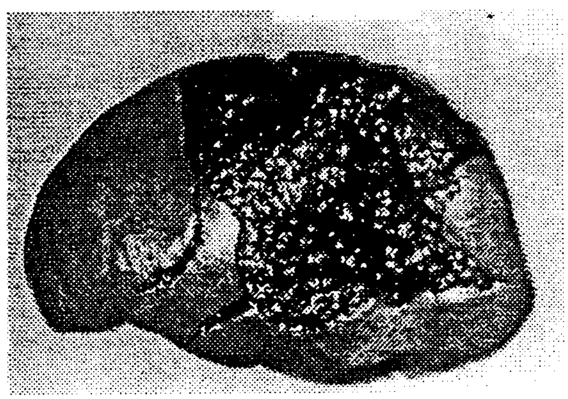


Fig. 15: Multiple spleen ruptures caused in a rigid wall left side impact

Repressurization of the brain vessels through the carotid arteries by using a pressure of 20 kPa ar .' a coloured solution shows escapes of the solution although the head was unloaded (Fig. 17); they are artifacts according the postmortem porous capillary wall.

On the other hand, in impactor tests of the front head we found contre coup subarachnoidal haemorrhages left and right (Fig. 18, Fig. 19), these without vascular repressurization (Mattern et al., 1994).

Generally, the haemorrhages observed in crash tests are small compared to those we see in autopsies of car accident cases.

Fig. 16 Liver rupture caused in a rigid wall left side impact

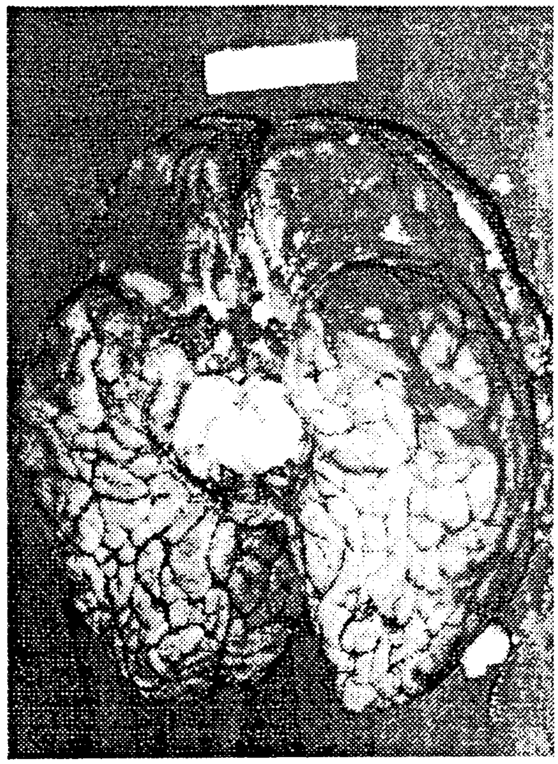


Fig. 17 Repressurization of brain vessels with escapes of the solution by unloaded head

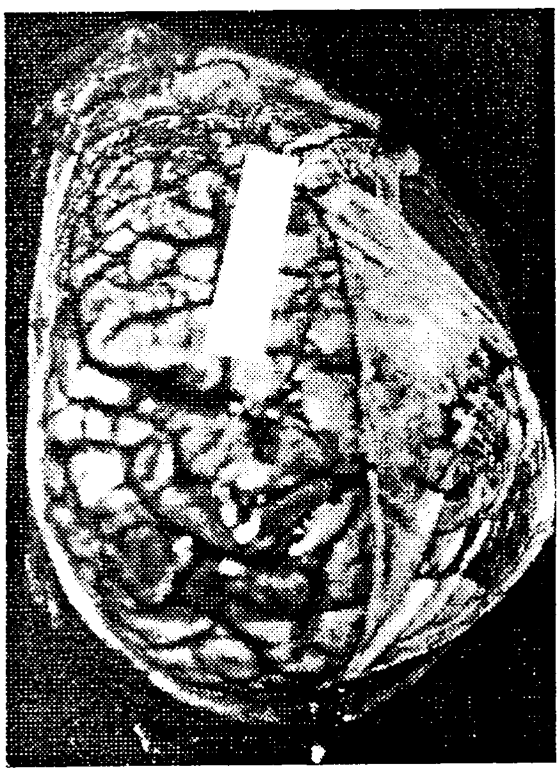


Fig. 18 Contre coup subarachnoidal haemorrhages left without vascular repressurization

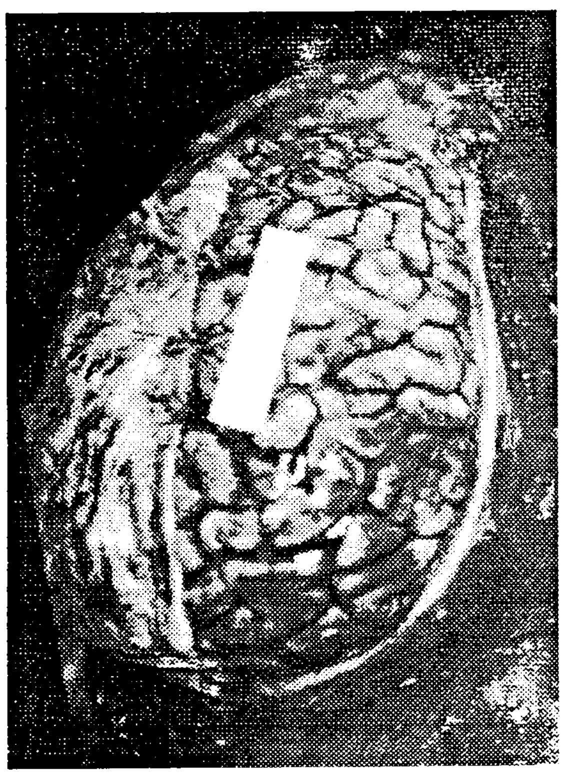


Fig. 19 Contre coup subarachnoidal haemorrhages right without vascular repressurization

Discussion

The influence of the cardiovascular pressurization to the human injury tolerance

According to our opinion, the cardiovascular pressurization can not have any effects to the fracture thresholds as they are predominantly determined by the morphology of the bony structure. The pressure in the bones, which is dependent upon the blood-pressure, doesn't play a part.

The injury threshold of organs with sufficient blood supply (like liver, spleen, kidney, brain) and of hollow organs (like heart, blood vessels) depends upon the initial stress of the organs. In living persons the initial stress is low in the diastole, high in the systole, it is intermittent with the pulse. Therefore, the injury risk depends whether the loading occurs in the systole, the diastole or in between. In the cadaver, the blood content of the organs and the filling condition of the hollow organs depends upon the cause of death and the kind of agony. Arteries are usually nearly bloodless and without initial stress; veins and capillaries could be overstretched by vascular congestion. This already effects the injury threshold. An additional cardiovascular pressurization in the cadaver produces a further influence regarding the injury threshold, the meaning of which is difficult to control. A constant cardiovascular pressurization is not the same as a comparable construction of the tension condition in a living person. In a positive -negative blood pressure simulation it remains doubtful which part of the pulse waves arrives in the loaded organs.

According to our knowledge there is no scientific study which displays that the cardiovascular pressurization in the cadaver would have led to an improvement of the biofidelity in the cadaver compared to the living. The cardiovascular pressurization seems to be an additional variable whose influence is unknown.

In regard to the differences of organ tensions dependent on blood pressure already in living persons and the differences of the blood filling conditions in the organs of cadavers we are convinced that cadaver tests without cardiovascular pressurization can be admitted in the basic collective of tests with and without the cardiovascular pressurization.

The influence of the pressurization of the pulmonary system to the bony fractures

The injury risks for bony fractures at the thoracic skeleton depend upon other things of the respiratory of the thorax. For the moment of the loading this can be an inspiration position, an expiration position or an intermediate state for the living person.

In the cadaver, the position of the thorax is determined, among other things, by the cause of death which has an effect to the lung volume (fluid content, blood content, air content). An additional pressurization of the pulmonary system takes place on the basis of these pre-alterations. Its influence to the lung volume is difficult to determine in the single case.

There is no paper which indicates that by a pressurization of the pulmonary system a higher biofidelity has been proofed compared to the one in a living person.

In all investigations with a permanent lung pressure (about 6 kPa) from the beginning of the loading and the occlusion of the trachea during the loading we have not obtained injury results which have shown an influence of the lung pressure to the injury severity compared with tests without pressurization of the pulmonary system.

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DISCUSSION

PAPER: **Preparation, Cardiopulmonary Pressurization and Rigor Mortis ... Cadaver Testing**

PRESENTER: Dr. Dimitrios Kallieris, University of Heidelberg

Q: David Porter, University of Louisville

I just had a very quick question. Did I understand you correctly; you said th... different injury patterns, depending on systolic versus diastolic pressure?

A: Which type of pressure?

Q: Maybe I misunderstood you, but I thought when you were talking about pre... vessel, you mentioned that there could be different injury patterns.

A: I presented all the findings and then they perform the autopsies from acciden... fractures, liver ruptures or spleen ruptures and the same, then we perform the ca... means that we have similar patterns, similar severities, injuries, then we compare ... accident severities.

Q: But did you compare systolic versus diastolic pressure or did I hear you wrong... you had stated that, depending on the initial conditions, whether there was systolic ... or diastolic blood pressure, that there would be different injuries.

A: Yes, this is the theory because the plexes shows that we have this type of injur...

Q: Along the same line, did you change the pulmonary pressure for expiration ve... through your tracheotomy or have you not looked at that?

A: We have similar pulmonary pressurization, then we close. We perform with an... we don't see any difference in their pattern or in their severity.

Q: Guy Nusholtz, Chrysler Corporation

Two items. One has to do with when you don't pressurize the brain and the effe... physical response. One of the things that we discovered some time ago was that ... pressurize the brain, this includes both the vascular and the cerebral spinal, you co... a thing called "brain flap," where the brain moves differentially much more than it ... and that has the potential to create additional injury.

The other is, I did a paper some time ago, I forgot whether it was the 30th or ... where we did a post-mortem versus live primate study in which we discovered that ... a definitive proof that pressurization returns the injury potential closer to right, but ... in the pressurized primate, the injuries were closer to the right than the unpressurize...

A: That was a comment?

Q: That was a comment. You don't have to respond.