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Biomechanical Analysis of traffic Accident related aortic Injuries over the past 40 Years

Stephan Brand, Christian Müller, Thorsten Facius, Sebastian Decker, Christian Krettek and Dietmar Otte

Hannover Medical School, Germany, with Traffic Accident Research Unit

ABSTRACT –
Still correlated with high mortality rates in traffic accidents traumatic aortic ruptures were frequently detected in unprotected car occupants in the early years. This biomechanical analysis investigates the different kinds of injury mechanisms leading to traumatic aortic injuries in today`s traffic accidents and how the way of traffic participation affects the frequency of those injuries over the years. Based on GIDAS reported traffic accidents from 1973 to 2014 are analyzed.
Results show that traumatic aortic injuries are mainly observed in high-speed accidents with high body deceleration and direct load force to the chest. Mostly chest compression is responsible for the load direction to the cardiac vessels. The main observed load vector is from caudal-ventral and from ventral solely, but also force impact from left and right side and in roll-over events with chest compression lead to traumatic aortic injuries.

Classically, the injury appeares at the junction between the well-fixed aortic arch and the pars decendens following a kind of a scoop mechanism, a few cases with a hyperflexion mechanism are also described. In our analysis the deceleration effect alone never led to an aortic rupture.

Comparing the past 40 years aortic injuries shift from unprotected car occupants to today`s unprotected vulnerable road users like pedestrians, cyclists and motorcyclists.

Still the accident characteristics are linked with chest compression force under high speed impact, no seatbelt and direct body impact.

KEYWORDS – Injury Mechanism, Aortic Ruptures, Biomechanics, In-Depth-Accident-Study, Traffic Accidents

Introduction

In this study, the occurrence and frequencies as well as the mechanisms and the causes of aortic ruptures are analyzed over the past 40 years. Traffic accidents from the years 1973 to 2014 are included with car occupants, occupants of trucks, pedestrians and riders of motorized two wheelers as well as bicyclists.

Earlier studies already showed the high percentage of lethal aortic injuries following vehicle accidents making these injuries the second most common death behind traumatic brain injuries.

Literature research on the biomechanical impact leading to fatal aortic injuries showed a shoveling effect on the thorax site transferring the load by the steering wheel following most frequently frontal impacts in unbelted situations.

Methods, Data Acquisition and Results

For this study accidents from the years 1973-2014 were analyzed. In order to avoid any bias in the database, the data collected in the study is compared annually to the official accident statistics and all police reported accidents for estimation of weighting factors. This process explains why the data captured by the research teams can be seen as representative for their areas .

As reference data the official accident data of the respective year from the German National Statistics Office (Destatis 2014 - Federal Bureau of Statistics) was used. As weighting factors the accident site (rural, urban), the main accident type (1 to 7) and the injury severity (slightly injured, severely injured, fatal) were used. This resulted in $2 \times 7 \times 3 = 42$ weighting factors for the analysis. This implies that the used absolute n-numbers in this study and the percentage numbers can't be directly converted into each other if weighting was done.

In total there were 41,670 traffic accidents with personal injuries on which 104,507 persons were involved and 53,851 injured persons. An aortic rupture was registered in 142 (0.26%) of the injured persons.

The frequencies of sustaining aortic injuries is pointed out in figure 1 below.

Figure 1: Injury Frequency of Aortic ruptures

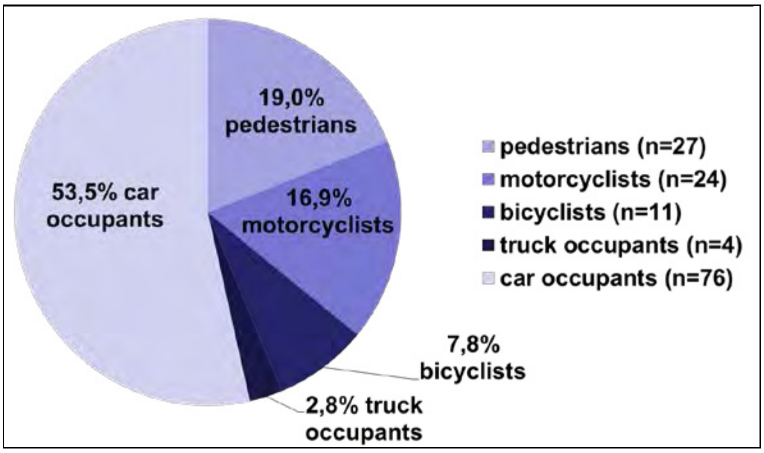

Table 1 shows the age distribution according to the kind of traffic participation.

Table 1: *Age distribution for the persons with aortic ruptures for the different kinds of traffic participation, cases with aortic rupture compared with cases without AR*

		with aortic rupture (n=142)			without aortic rupture (n=53,709)		
		< 30 years	30-59 years	> 60 years	< 30 years	30-59 years	> 60 years
Kind of traffic participation	**Car occupants** n=76 with AR	48.2%	25.8%	26.0%	45.0%	43.5%	11.5%
	Pedestrians n=27 with AR	5.0%	59.3%	35.7%	46.2%	27.5%	26.3%
	Motorcyclists n=24 with AR	70.3%	28.6%	1.1%	54.5%	39.9%	5.6%
	Bicyclists n=11 with AR	16.9%	25.7%	57.4%	42.3%	39.5%	18.2%
	Truck occupants n=4 with AR	-	100%	-	31.4%	52.0%	16.6%
	Overall n=142 with AR	**42.9%**	**33.4%**	**23.7%**	**45.0%**	**41.5%**	**13.5%**

Table 2 and 3 show the incidence and location of observed aortic injuries over the past 40 years according to traffic participation.

Table 2: *Cases of aortic ruptures by kind of traffic participation and calendar year grouping*

		Kind of traffic participation				
		Car occupants n=76	**Pedestrians n=27**	**Motorcyclists n=24**	**Bicyclists n=11**	**Truck Occupants n=4**
Accident years	**1973-1975**	8	-	1	2	-
	1976-1978	11	2	2	1	-
	1979-1981	6	2	-	-	2
	1982-1984	13	1	2	2	-
	1985-1987	3	1	3	-	-
	1988-1990	6	4	1	2	-
	1991-1993	2	3	-	1	-
	1994-1996	3	1	-	-	-
	1997-1999	3	1	2	1	1
	2000-2002	5	4	3	-	1
	2003-2005	9	2	4	2	-
	2006-2008	4	4	3	-	-
	2009-2011	2	1	2	-	-
	2012-2014	1	1	1	-	-

Table 3: *Location of the aortic ruptures for the different kinds of traffic participation*

		Location of aortic rupture			
		ascending	**arch**	**descending**	**unknown**
Kind of traffic participation	**Car occupants** n=76	6 7.9%	15 19.7%	27 35.5%	28 36.9%
	Pedestrians n=27	4 14.8%	2 7.4%	13 48.2%	8 29.6%
	Motorcyclists n=24	3 12.5%	2 8.3%	14 58.4%	5 20.8%
	Bicyclists n=11	3 27.3%	1 9.1%	4 36.3%	3 27.3%
	Truck occupants n=4	1 25.0%	1 25.0%	-	2 50%
	Overall n=142	**17 12.0%**	**21 14.8%**	**58 40.8%**	**46 32.4%**

Figure 2 shows the structure of the aorta and the distribution of the aortic ruptures for all kinds of traffic participation. Mostly the descending part of aorta was ruptured (40.8%), followed by the arch of the aorta (14.8%) and the ascending part of the aorta (12.0%).

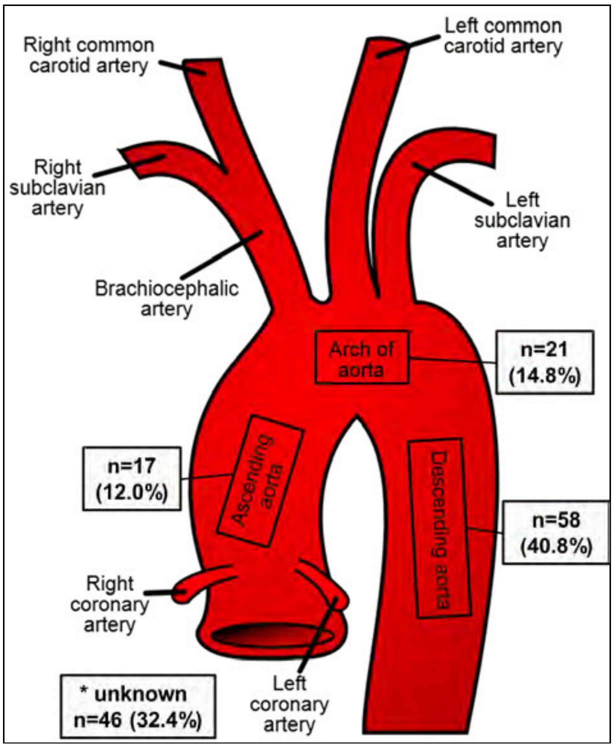

Figure 1: *Location of the aortic ruptures for all kinds of traffic participation*

Injury Mechanisms and Accident Load Conditions of Aortic ruptures

The typical injury mechanism of car occupants and motorcyclists is shown in figures 3-5 indicating the caudal-ventral force load in both groups.

Figure 3: *Typical injury mechanism of an aortic rupture for car/truck occupants: Caudal or caudal-ventral thoracic load (red arrow)*

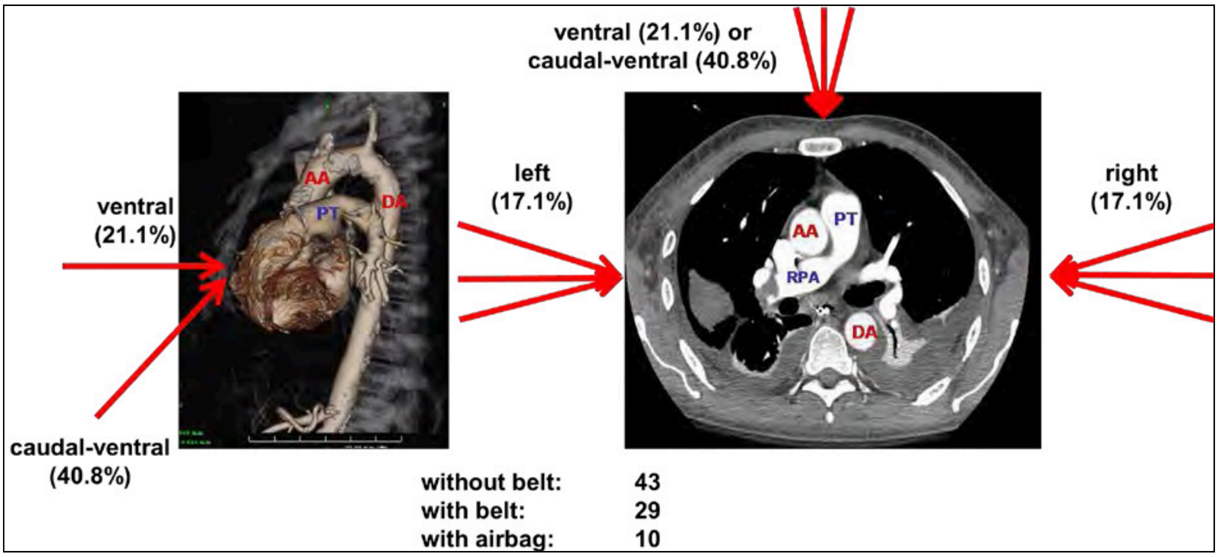

Figure 4: *Direction of load to the thorax and corresponding injury mechanism for car occupants (AA: ascending aorta; DA: descending aorta; PT: pulmonary trunk; RPA: right pulmonary artery)*

Figure 5: *Typical injury mechanism of an aortic rupture for motorcyclists: Caudal or caudal-ventral thoracic load (red arrow) respectively a frontal or lateral impact of the thorax to the roof, A-pillar or side compartment of the car/truck*

Figure 7 therefore indicates the injury mechanism for vulnerable road user like pedestrians with a high lateral loading at the thoracal site.

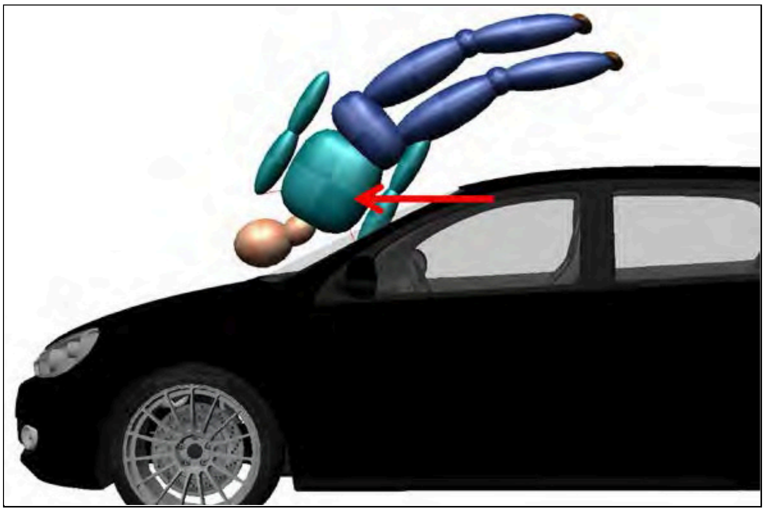

Figure 2: *Typical injury mechanism of an aortic rupture for pedestrians: Lateral thoracic load (red arrow.) The thorax impacted the roof structure during the wrap around movement within a rotation of the full body as a result of high speed of the car (>80 km/h).*

The three different types of injury mechanims leading to aortic ruptures are shown in figure 8 (torsion, bending and shearing forces (according to Rückert et al 2011)).

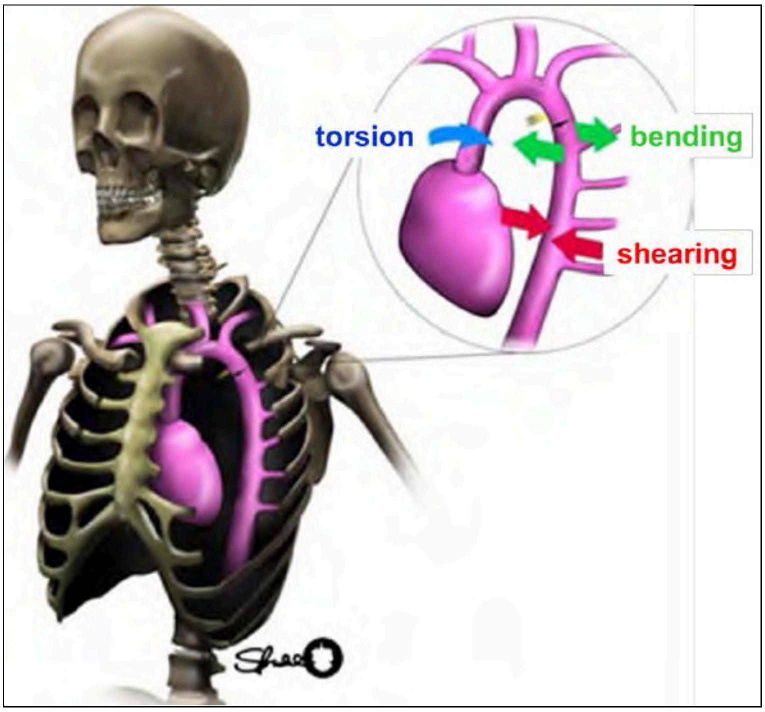

Figure 3: *Typical analyzed injury mechanism of the traumatic rupture of the aorta: Torsion (blue), bending (green) and shearing forces (red) at the thoracic aorta (picture from Rückert et al. 2011; slightly modified)*

Discussion and Conclusion

A total of 142 accident victims were analyzed over the past 40 years.
Detailed information based on GIDAS-data were acquired.
Our analysis showed that especially traffic accidents characterized by high speed collisions were associated with aortic injuries.
A main force vector directing caudal-ventral to the chest leading to a major chest deformation was observed as mainly associated with blunt aortic ruptures.
Non-use of seat belt as well as earlier models of steering wheels and earlier layouts of dashboard design were highly linked with severe chest and aortic injuries. Nowadays with the improvement of car safety features like airbags, improved constructions of the steering column lead to a decrease of decelerating aortic ruptures.
In todays traffic accidents a higher percentage of blunt chest and aortic injuries was found in a lateral thoracal loading in lateral compression accidents with high velocity impacts.
Ongoing improvements in active and passive car safety as well as protective applications for vulnerable road user is expected to even lower the number of detected fatal blunt aortic injuries.