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The volume of postmortem bleeding in drowning victims having sustained blunt thoracic aortic injury resulting from vehicular accidents

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Abstract: Recent studies have shown that 1500 mL of blood found in the intrapleural cavity due to blunt thoracic aortic injuries, should be considered as postmortem in the cases of immediate deaths. Considering that drowning lasts for 4 to 5 minutes, the question is about if that time period has an influence to the volume of antemortem exsanguinated blood if accompanied with aortic rupture. A retrospective study determined two groups out of which the first one consisted of vehicle occupants who fell in the river canyon and died from drowning accompanied by traumatic aortic rupture. The second group was comprised of vehicle occupants injured in conventional vehicle accidents where the occupants died from bleeding due to aortic rupture. The ROC curve is used to evaluate the cut-off value related to the volume of postmortem bleeding originating from aortic rupture and total exsanguinated blood. The study showed that the time elapsed during drowning did not significantly influence the volume of antemortem and postmortem blood. In cases of the blunt thoracic aortic injury with concomitant drowning as cause of death, volumes less than 1400 mL of intrapleural bleeding should be considered as mostly postmortem.
Key Words: aortic rupture, bleeding, canyon death, drowning, postmortem bleeding.

Evaluation of collected data from road traffic accidents shows that a blunt thoracic aortic injury (BTAI) occurs in less than 1 % of all motor vehicle crashes; however, this injury is responsible for 15 – 16 % of road traffic accident deaths [1]. Up to 80 – 85 % of patients die before arriving at the hospital [2]. Of those vehicle occupants who survive the initial injury, a majority (i.e., 94 %) will die without surgical treatment [2, 3]. Baque P *et al.* [4] experimentally demonstrated that the deceleration force in the isthmus of the aorta is significantly higher for 17 % than the one recorded in the heart. This difference in deceleration represents the fundamental mechanism of BTAI: sudden stretching in the isthmus of the aorta. Furthermore, there are three additional mechanisms of the BTAI: two hemodynamic mechanisms (i.e., a sudden increase in intravascular pressure and the water-hammer effect), and a physical mechanism related to the osseous pinch [4, 5].

Early works [6, 7] and several recent studies [8, 9] showed that the postmortem bleeding of a volume of blood is an already proven phenomenon. Zivkovic *et al.* [9] showed that 1500 mL of blood found in the intrapleural space due to BTAI should be considered as postmortem in the cases of almost immediate death caused by pontomedullar laceration. Brainstem lacerations are associated with hinge or ring fractures, fractures of the upper cervical spine, and atlanto-occipital fractures/luxations, and death is almost always immediate [6].

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Drowning deaths in freshwater typically occur over a four to five minute period, while seawater drowning typically occurs over an eight to twelve minute period [10]. Polson and Gee [11] state that estimated time from immersion to the death from drowning lasts from two to twelve minutes.

The aim of this study is to determine the postmortem volume of blood in the cases of vehicle occupants who fell in the river canyons and subsequently died from drowning accompanied with BTAI. Considering that freshwater drowning lasts for four to five minutes, the question investigated in this study is if this time period has an influence on the volume of antemortem exsanguinated blood.

MATERIALS AND METHODS

Montenegro is a small mountainous South European country with many dangerous roads meandering throughout its river canyons. When a car accident occurs on these roads, the vehicle can sometimes fall into the river at the base of the canyon, which most often results in the drowning of the vehicle's occupants. The accidental deaths from this specific type of car accident serve as the basis of data for this study.

A retrospective case-control autopsy study determined two groups of subjects. The first groupis comprised of vehicle occupants who fell into the river canyon and died from drowning accompanied by bleeding primarily from BTAI (i.e., aortic rupture accounts for the greatest volume of blood while the secondary sources of bleeding originate from other ruptured organs and vessels).

The second groupis comprised of vehicle occupants whose injuries occurred inconventional vehicle accidents (i.e., not from canyon falls) and who died primarily from BTAI bleeding (i.e., secondary sources of bleeding originate from other ruptured organs and vessels, just as with the first group).

All aortic ruptures were complete, involving the entire thickness of the aortic wall, in it's whole or partial circumference. Cases with large bone fractures (e.g., pelvic bones and the long bones of the lower extremities) were excluded from this study due to the difficulty associated with precisely determining the exsanguinated blood volume around these fractures. Additionally, cases where the intra-abdominal bleeding exceeded 25 % of the measured intrapleural bleeding and cases with severe lung ruptures were excluded from this study, as well. The limit of 25 % was estimated statistically (by comparing correlation coefficients) that above it there would be no influence to the results.

For each case presented in this paper, the cause of death was established by performing a full autopsy. The exact volume of exsanguinated blood was measured during the autopsy. The diagnosis of drowning presented macroscopically by emphysema aqueous, was confirmed microscopically.

Results were statistically evaluated for this paper using the descriptive statistics tools which include: the Kolmogorov-Smirnov test (i.e., testing for distribution normality), the Student t-test, the non-parametric Z-test for comparing proportions, Student T-test, and the Pearson correlation. A p-value below 0.05 was considered as significant, and a p-value below 0.01 was considered highly significant. The receiver operating characteristic curve (ROC curve) is useful for estimating the accuracy of a prediction. The ROC assists establishing the cut-off score characterized by the optimal ratio between sensitivity and specificity (or to maximize proportions

Table 1. Volume of exanguinated blood for both groups (SD – standard deviation; SE – standard error; Min – minimum; M – maximum)

		First group	Second group	Significance of differences (Student T-test)
Volume of exanguinated blood from BAI	Mean	1285	1554	t=-2.147, d*f*=29, p=0.042
	SD	328	344	
	SE	102	112	
	Min	750	450	
	Max	1900	2200	
Volume of exanguinated blood from other organs and vessels	Mean	259	426	t=-2.456, d*f*=29, p=0.023
	SD	83	58	
	SE	34	34	
	Min	0	0	
	Max	450	250	
Total volume of exanguinated blood	Mean	1544	1980	t=-4.643, d*f*=29, p=0.000
	SD	329	311	
	SE	101	79	
	Min	900	450	
	Max	2150	2550	

between true positive ones and true negative ones). The y-axis represents the sensitivity with values ranging from 0.0 to 1.0 (i.e., the sensitivity values are normalized to 1.0). The x-axis represents one minus the specificity or proportion of false positive ones. If using normalized units, the area under the curve (AUC) is equal to the probability that a classifier will rank a randomly chosen positive case higher than a randomly chosen negative case (i.e., the AUC represents the accuracy of the test).

RESULTS

The first group consisted of 32 subjects (mean age 43 ± 16.4, min 18, max 69) was compared with 48 subjects of second group (mean age 40 ± 13.7, min 16, max 73). No significant differences were found across age between both groups ($p = 0.265$). The male-female ratio was 91 % in the first group and 94 % in the second group, and the Z-test showed no significant difference for sex ratios between the two groups ($p = 0,855$).

Drivers are dominantly fatally injured in both groups. Z-test results showed no significant difference for percentages of drivers, front-seat passengers, or back-seat passengers ($p > 0.05$) between the groups. According to the statistical analysis, the two groups are homogenous across age, sex, and type of injured occupants.

Table 1 shows the volumes of exsanguinated blood. T-test results showed significant differences in all parameters between the groups.

For both groups there are significant correlations for the aortic bleeding and the volume of total bleeding (i.e., the first group: Pearson correlation 0.901, $p < 0.000$; the second group: Pearson correlation 0.641, $p < 0.001$), However, the difference between these two correlations is not significant (Mann-Whitney U-test, $p = 0.567$).

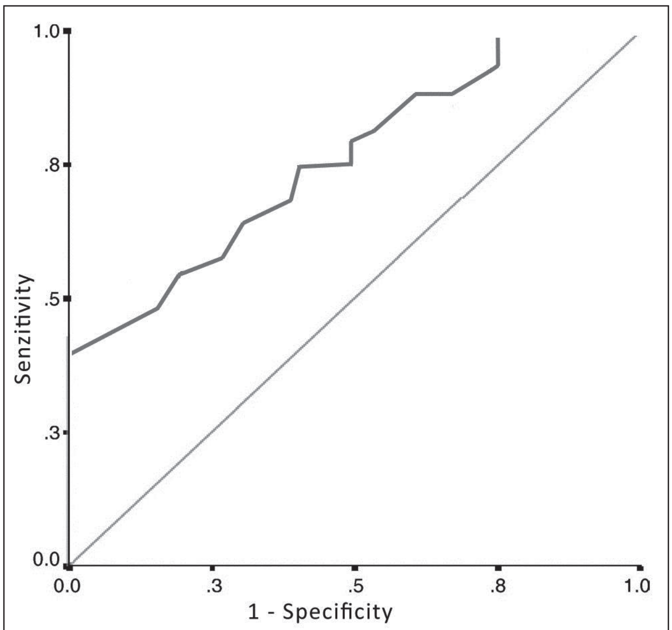

Figure 1. ROC curve for the cutoff value of 1400 mL, with best sensitivity / specificity ratio.

The ROC curve is used to evaluate the volume of postmortem bleeding producedby aortic rupture (Fig. 1). The AUC is 0.808, and the cut-off value for thevolume of intrapleural bleeding is 1400 mL. This cut-off value indicates a sensitivity of 64.6 % and a specificity of 71.8 %.

DISCUSSION

The paper under review here belongs to a volume of studies which try to determinate the volume of postmortem exsanguinated blood [8,9]. The specific circumstances surrounding the vehicle accidents in river canyons provide a unique problem to investigate. We aim to investigate the origins of the exsanguinated blood during the period (i.e., four to five minutes) when vehicle accident occupants are able to survive the accident trauma.

T-test results showed highly significant differences for all parameters between the two groups, which demonstrates the observation that subjects in the drowning group have less total bleeding, namely including exsanguinated blood from BTAI and other ruptured organs and vessels.Our investigation of exsanguinated blood volume during the survival period for river canyon vehicle accident victims is based on the same methodology presented in the study by Zivkovic *et al.* [9]. They demonstrated that intrapleural bleeding volumes less than 1500 mL should be considered mostly as postmortem in origin for cases showing BTAI with concomitant pontomedullar brainstem laceration which typically resulted in immediate death. Using the cut-off value (i.e., 1500 mL), they found the AUC, which illustrates the reliability and accuracy of the test, to be 0.789. This AUC indicates a sensitivity of 60 % and a specificity of 78.9 %.

In our investigation, we found a cut-off value of 1400 mL, which was obtained by the ROC curve, too. Furthermore, the accompanying AUC was 0.808. This value of AUC indicates a sensitivity of 64.6 % and a specificity of 71.8 %. These results suggest that, for cases with BTAI and further intrapleural bleeding with concomitant drowning, intrapleural bleeding volumes less than 1400 mL should be considered mostly as postmortem in origin. In these cases, drowning should be considered the sole cause of death. Conversely, drowning and exsanguination should be considered as the competing cause of death in cases showing volumes of intrapleural bleeding exceeding 1400 mL.

Due to thehigh correlations in both groups between the volume of exsanguinated blood from BTAI and the total exsanguinated blood, the intrapleural volume of blood accurately represents the total volume of bleeding.

With the exclusion criteria in mind (i.e., fractures of big bones, large lung ruptures, and intra-abdominal bleeding volume less than 25 % of the intrapleural bleeding volume), measuring intrapleural bleeding should be considered as a relevant method useful for determining the origin of postmortem or antemortem bleeding in any similar autopsy case during the estimated survival period from four to five minutes. This suggests that the data is useful for not only concomitant drowning and BTAI cases, but it is also useful for all other cases of concomitant causes of death with a four to five minute estimated survival period.

Comparing the ROC curves from our investigation and Zivkovic *et al.*, there is no statistical significance between the two curves ($p > 0.05$). Therefore, the survival period from four to five minutes, which is the time difference between the immediate death and death from drowning, does not significantly affect the volume of postmortem bleeding from BTAI, nor the total exsanguinated blood. In the cases of demised vehicle occupants who died from drowning accompanied by traumatic aortic rupture, the volume of antemortem intrapleural bleeding is only slightly higher, compared to the cases of vehicle occupants who died from pontomedullar brainstem laceration accompanied with bleeding from traumatic aortic rupture.

Relevant literature has provided differing data opposed to our results. Di Maio experimentally demonstrated a possible volume of postmortem bleeding by cutting large blood vessels, and showed blood volumes between 300 to 500 mL of blood in body cavities [7]. Gordon *et al.* [6] obtained between 50 to 1000 mL of postmortem bleeding from postmortem wounds (i.e., using a scalpel through skin and rib interspace, into the lungs). Nikolic *et al.* [8] experimentally showed that the possible volume of postmortem bleeding could be about 600 mL (i.e., for the cases of sudden and accelerated deaths, cases of strangulation and suffocation, and also the cases of sudden natural deaths), by cutting the thoracic aorta at the level of the fourth thoracic vertebra. Greater volumes of postmortem bleeding obtained from the study by Zivkovic *et al.* [9] and our investigation may be explained by self-excitability heart potential for a very short period after the brain death.

CONCLUSION

The volume of aortic bleeding reliably reflects the total volume of bleeding in both groups. In cases of the BTAI with any concomitant cause of death which represents accelerated death for the given survival period, volumes less than 1400 mL of intrapleural bleeding should be considered as mostly postmortem. Cases with intrapleural bleeding exceeding 1400 mL from BTAI with any concomitant cause of death related with the accelerated death should consider these causes of death as the competing causes. The study showed that the elapsed drowning period (four to five minutes) did not significantly influence the volume of antemortem and postmortem bleeding comparing to the immediate deaths.

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