Original Article

A Study of the Association Between Blunt Thoracic Aortic Injury and a Type of Collision in Fatal Motorcycle Accident

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Abstract

Introduction/ Objective: To determine the association between blunt thoracic aortic injury (BTAI) and the type of collision in fatal motorcycle riders in Thai postmortem cases.

Methods: Data from autopsy reports of motorcycle riders who were sent for medico-legal autopsies at the Department of Forensic Medicine, Siriraj Hospital, Mahidol University between 1st January 2018 and 31st December 2020 and presented with BTAI were retrospectively reviewed. Sex, age, height and weight, causes of death, types of collision, details of aortic injuries and associated injuries were recorded. Descriptive statistics, Mann-Whitney U test and contingency table Chi-square test were analyzed where it was suitable.

Results: There were 180 cases recruited in this study and 173 cases (96.11%) were male. The majority of the collision was frontal collision (152, 84.4%). The most common BTAI site was the aortic isthmus (48.3%) followed by ascending aorta (32.8%). The proportion of ascending aortic injury in the frontal collision was significantly higher than that of a non-frontal collision ($P = .011$). The average sites of ascending aortic injury and aortic isthmus injury were approximately 1 cm above the sino-tubular junction and 1 cm distal to the left subclavian artery, respectively. Injuries to ascending aorta and isthmus were significantly associated with sternal fracture and cardiac laceration ($P < .01$). Aortic isthmus injury was also associated with pelvic fracture ($P = .03$). Descending aortic injury was associated with thoracic spine fracture ($P < .01$).

Conclusions: Injuries to the isthmus were the most common BTAI in motorcycle riders followed by ascending aorta. Sternal fracture and cardiac laceration were associated with injuries to the isthmus and ascending aorta.

Keywords: Blunt thoracic aortic injury (BTAI), Motorcycle rider, Collision, Postmortem

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Introduction

Blunt thoracic aortic injury (BTAI) is one of the most common causes of death in trauma patients. BTAI was commonly related to high-energy blunt trauma like motor vehicle accidents, falls from height, and pedestrian injuries.[1] An estimate of 70-90% of patients with BTAI was dead before hospitalization and approximately 44% of patients eventually died in hospital after arrival.[2] The incidence of BTAI in fatal motor vehicle accidents in USA from 1993 to 2004 was approximately 18.9 ± 1.8%.[3] However, there is no incidence data of BTAI in fatal traffic accident in Thailand. The majority of BTAI resulted from frontal collisions, offset frontal collisions and near-side collisions.[3,4] The previous study showed that the aortic isthmus was the most common site of BTAI.[5-7] According to previous studies, it was suggested that the mechanisms of BTAI mainly consisted of four principles. The first two mechanisms were abrupt deceleration with stretching of the aortic isthmus and osseous pinch theory.[8,9] These two mechanisms were based on physical mechanism related to anatomical position of the aorta and some physics parameters.[8,9] The other two mechanisms were a sudden increase of intraluminal pressure in the aorta after chest compression force and water-hammer effect which was related to the effect of high-pressure waves of intraluminal fluid against the aortic wall.[8,9] These two mechanisms were related to hemodynamic mechanism which was related to critical pressure threshold or ultimate tensile strength of aorta when intravascular pressure was increased.[8,9] However, these four theories could not explain several conditions of aortic injuries. According to the CIREN study, it was suggested that BTAI (particularly at the isthmus) was related to the Archimedes lever hypothesis.[10-12] The aortic isthmus area was encountered the maximal stress and strain under high impact energy and highly prone to aortic injury at this point.[10-12] Most of the studies above were based on the study of car crash and dead bodies were mainly in the front car seat. Pelletti G et al., conducted a study in motorcycle riders who had BTAI and they found that combined mechanisms should be a suitable model for BTAI.[13] In addition, although the isthmus was still the most common site of injury, the proportion of injuries to ascending aorta was also striking.[13] All of these findings suggested that BTAI in different types of a traffic accident may have different mechanisms.

However, a motorcycle accident is more common than other types of traffic accident in Thailand.[14] Chadbunchachai W et al., reported that the majority of Thai people dead in a traffic accident were young people (not greater than 45 years old).[14] Approximately 80% of traffic accidents in Thailand involved motorcycle accidents and this figure was relatively steady from 1997 to 2009.[14] In addition, it was found that motorcycle riders were prone to suffer from serious injuries particularly the chest and abdominal injuries compared to pillion passengers.[15] In Thailand, there was a report from Charaschaisri W. who studied the comparison of BTAI in autopsy findings between motorcycle riders and pillion passengers.[16] This paper indicated that the most common injury of BTAI occurred at aortic isthmus (57.7%) and sternal fracture and rib fractures were significantly associated with BTAI.[16] Due to the limited number of subjects (n = 39) and the concentration only in associated sternal and rib fractures, the author suggested for further study to obtain more data for interpretation.

Thus, the main objective of this study is to determine the association between the characteristics of BTAI and types of motorcycle collisions. In addition, the association between the sites of BTAI and accompanying injuries is also investigated as the second objective. This study concentrates on motorcycle riders because they are commonly involved in medico-legal autopsy in Thailand. These data will be potentially useful for practical interpretation in BTAI in a fatal motorcycle accident.

Methods

A retrospective study was conducted from autopsy reports and attached police records of motorcycle accident cases performed at the Department of Forensic Medicine, Siriraj Hospital, Mahidol University, Thailand between 1st January 2018 and 31st December 2020. The inclusion criteria were data from Thai motorcycle riders who were 18 years old or over and the mechanisms of injuries in those cases were confirmed from police records including crime scene investigation profiles, and details of CCTV and/or front cameras from vehicles in the crime scene. The exclusion criteria were data from run-over injuries and data from cases that had multiple crashes in accidents.

Data collected from autopsy reports included sex, age, height, and weight. Body mass index (BMI) was then calculated from height and weight. Causes of death were divided into three categories: head/neck injuries, chest injuries and abdominal/pelvic injuries. Then, types of collisions were recorded and first divided into two types: frontal and non-frontal collision. Frontal collision in this study also included offset frontal collision. Non-frontal collision included side impact and rear impact. Next, a frontal collision was divided into 2 categories: motorcycle-to-object (for example, motorcycle-to-electric pole, tree, or parked truck) and motorcycle-to-moving vehicle (for example, motorcycle-to-car). Then, the sites of aortic injuries were recorded and divided into four sites: ascending aorta, arch of aorta, isthmus and descending aorta. This study defined the isthmus as the aortic site within 2 centimeters distal to left subclavian artery.[17] The number of sites of aortic injuries was also recorded because some cases had multiple sites of aortic injuries. The aortic injuries were recorded, starting from the distal to the sino-tubular junction to descending aorta which was divided into 4 parts: ascending aorta, arch of aorta, isthmus, and descending aorta. The distances of aortic injuries from sino-tubular junction (for injuries to ascending aorta and arch of aorta) or left subclavian artery (for injuries to isthmus and descending aorta) were collected. The measurement of aortic injury from sino-tubular junction was performed from the imaginary line connecting aortic valve commissures (which were normally above the coronary orifice around 2 mm) direct to the site of aortic injury at ascending aorta and arch of aorta.[18] The measurement of aortic injury from left subclavian artery was performed from lateral border of left subclavian arterial wall direct to the site of aortic injury at isthmus and descending aorta. The associated injuries in these cases were recorded as described below:

1. There were three types of head injuries: fracture skull/base of the skull, meningeal hemorrhage (including epidural hemorrhage, subdural hemorrhage, and subarachnoid hemorrhage), and traumatic brain injuries (including brain contusion, brain laceration, traumatic axonal injuries intraventricular hemorrhage, ponto-medullary contusion or laceration and secondary impact injuries). However, concussion was not included in this study because it did not produce a pathological finding.

2. Vertebral injuries were recorded for two main types: cervical spine and thoracic spine fractures.

3. Three chest injuries were recorded: sternal fracture, rib fractures, and cardiac laceration. Rib fractures were classified into two categories: rib fractures not more than four and rib fractures more than four on each side. There was a report of increased morbidity and mortality when more than four rib fractures in trauma patients were detected.[19,20]

4. Abdominal/pelvic injuries were divided into three main types: liver laceration, splenic or kidney laceration, and pelvic fracture.

5. Four sites of fractures of extremities were recorded including the humerus, distal end radius/ulnar (wrist), femur, and tibia.

Data entry in this study was verified by proof-reading data method that a back-office staff in the Department entered data in the computer and the first author was responsible for checking data against the initial data recording. Blood alcohol concentration and place of death were not included in this data entry because these two factors were not related to chest injuries including aortic injuries and the time interval to death.[21,22]

The statistical analysis was performed using the program IBM SPSS® Statistics for Windows version 21. Descriptive statistics including mean, median and standard deviation (SD) were analyzed. Then, the Kolmogorov-Smirnov test and Levene's test for equality of variance were tested for continuous variables. Mann-Whitney U test were employed for the comparison of continuous variables because data were not normally distributed. For categorical data, contingency table chi-square test was performed for analysis. As increased age affected aortic integrity due to the effect of atherosclerosis, anthropological parameters including age and BMI were also analyzed for the association with sites of BTAI. The statistical significance was set at $P < .05$.

This study was approved by the Siriraj Institutional Review Board, Faculty of Medicine, Siriraj Hospital, Mahidol University (Certificate of Approval No. Si 128/2021, Research Project No. 010/2564).

Results

There were 180 subjects recruited in this study. The majority of cases were male (173 subjects, 96.11%). The mean age was 34.26 ± 13.27 years old (18-78 years old). The average BMI was 24.72 ± 4.94 kg/m^2 (16.03-44.13 kg/m^2). The main cause of death in this study was head/neck injury (46.7%) followed by chest injury (42.8%) and abdominal/pelvic injury (10.6%), respectively. The majority of collision was frontal collision (84.4%) and more than a half of frontal collision was motorcycle-to-object. The comparison of types of collisions across age and BMI was shown in Table 1. Only age was significantly different between two subtypes of frontal collision. When causes of death were also considered, there was not any significant association between causes of death and types of collision.

Table 1 Demographic data of BTAI including age and BMI against types of collision

Types of collision		**N**	**Age**	***P*-value**	**BMI**	***P*-value**
Frontal	Object	87 (57.2%)	31.32 ± 11.49	.012	25.06 ± 5.60	> .05
	Vehicle	65 (42.8%)	36.38 ± 13.19		24.17 ± 4.43	
Frontal (total)		152 (84.4%)	33.49 ± 12.46	> .05	24.68 ± 5.13	> .05
Non-frontal		28 (15.6%)	38.43 ± 16.67		24.91 ± 3.76	
Total		180	34.26 ± 13.27		24.72 ± 4.94	

The percentage of sites of aortic injuries related to types of collision could be shown in Table 2. It was found that injury to the isthmus was still the most common site of injury both in frontal and non-frontal collision (approximately a half of total cases) followed by ascending aorta (approximately one-third of total cases). Only frontal collision (including both types) had significantly higher rate of ascending aortic injury compared with non-frontal collision (*P* = .011). However, there was no any significant association between other sites of aortic injuries and types of collision.

Table 2 The distribution of sites of BTAI against types of collision

Types of collision		**Ascending**	**Arch**	**Isthmus**	**Descending**	**Two sites**	**Total**
Frontal	Object	33 (37.9%)	8 (9.2%)	36 (41.4%)	2 (2.3%)	8 (9.2%)	87
	Vehicle	22 (33.8%)	5 (7.7%)	32 (49.2%)	2 (3.1%)	4 (6.2%)	65
P-value[1]		> .05	> .05	> .05	> .05	> .05	
Frontal (total)		55 (36.2%)	13 (8.6%)	68 (44.7%)	4 (2.6%)	12 (7.9%)	152
Non-frontal		4 (14.3%)	2 (7.1%)	19 (67.9%)	3 (10.7%)	0 (0%)	28
P-value[2]		.011	> .05	> .05	> .05	Not defined	
Total		59 (32.8%)	15 (8.3%)	87 (48.3%)	7 (3.9%)	12 (6.7%)	180

P-value[1] = comparison of rates of BTAI between two types of frontal collision

P-value[2] = comparison of rates of BTAI between frontal and non-frontal collision

Not defined = *P*-value was not determined because one cell in contingency Chi-square test was zero

The findings of this study showed that there were two most common sites of aortic injuries: approximately 1 cm above the sino-tubular junction of ascending aorta and approximately 1 cm distal to the left subclavian artery as shown in Table 3.

Table 3 The distribution of locations of BTAI

Distance	From sino-tubular junction		From left subclavian artery	
	Ascending	Arch	Isthmus	Descending
Mean ± SD (cm)	1.25 ± 0.94	5.81 ± 0.46	1.19 ± 0.67	4.92 ± 1.76
Range (cm)	0.3-4	5-6.5	0-2	3-8

When associated injuries were considered from total cases, it was found that the most common injuries associated with BTAI were liver laceration followed by multiple rib fractures (> 4 ribs) and skull/base of skull fracture, respectively as described in Table 4. Cardiac laceration was significantly associated with frontal collision whereas thoracic spine fracture was significantly associated with non-frontal collision.

Table 4 The comparison of associated injuries against types of collision in BTAI

Associated injuries	Frontal				Non-frontal	*P*-value[2]	Total
	Object	Vehicle	*P*-value[1]	Total			
Sternal fracture	36 (41.4%)	23 (35.4%)	> .05	59 (38.8%)	8 (28.6%)	> .05	67 (37.2%)
Rib fractures (>4)	44 (50.6%)	30 (46.2%)	> .05	74 (48.7%)	18 (64.3%)	> .05	92 (51.1%)
Cardiac laceration	39 (44.8%)	23 (35.4%)	> .05	62 (40.8%)	4 (14.3%)	.007	66 (36.7%)
Skull/base of skull fracture	50 (57.5%)	26 (40%)	.033	76 (50%)	12 (42.9%)	> .05	88 (48.9%)
Meningeal hemorrhage	32 (36.8%)	17 (26.2%)	> .05	49 (32.2%)	6 (21.4%)	> .05	55 (30.6%)
Traumatic brain injury	40 (46.0%)	28 (43.1%)	> .05	68 (44.7%)	10 (35.7%)	> .05	78 (43.3%)
Cervical spine fracture	21 (24.1%)	17 (26.2%)	> .05	38 (25%)	5 (17.9%)	> .05	43 (23.9%)
Thoracic spine fracture	15 (17.2%)	14 (21.5%)	> .05	29 (19.1%)	12 (42.9%)	.006	41 (22.8%)
Liver laceration	55 (63.2%)	38 (58.5%)	> .05	93 (61.2%)	19 (67.9%)	> .05	112 (62.2%)
Spleen/kidney laceration	16 (18.4%)	18 (27.7%)	> .05	34 (22.4%)	11 (39.3%)	> .05	45 (25%)
Pelvic fracture	10 (11.5%)	17 (26.2%)	.019	27 (17.8%)	7 (25%)	> .05	34 (18.9%)
Femoral fracture	25 (28.7%)	25 (38.5%)	> .05	50 (32.9%)	5 (17.9%)	> .05	55 (30.6%)
Tibial fracture	14 (16.1%)	17 (26.2%)	> .05	31 (20.4%)	5 (17.9%)	> .05	36 (20%)
Humeral fracture	15 (17.2%)	6 (9.2%)	> .05	21 (13.8%)	6 (21.4%)	> .05	27 (15%)
Wrist fracture	16 (18.4%)	12 (18.5%)	> .05	28 (18.4%)	3 (10.7%)	> .05	31 (17.2%)

P-value[1] = comparison of associated injuries between two types of frontal collision

P-value[2] = comparison of associated injuries between frontal and non-frontal collision

When the contingency table Chi-square test was applied for the association between types of collision and associated injuries, it was found that frontal collision (including both types) was associated with cardiac laceration compared with non-frontal collision ($P = .007$) whereas non-frontal collision was associated with thoracic spine fracture compared with frontal collision ($P = .006$). For other comparisons, there was no significant association found between types of collision and associated injuries. When the analysis was performed between two types of frontal collisions, it was found that frontal collision in the motorcycle-to-object group was associated with skull and/or skull base fracture compared with the motorcycle-to-vehicle group ($P = .033$) whereas frontal collision in the motorcycle -to-vehicle group was associated with pelvic fracture compared with the motorcycle-to-object group ($P = .019$).

The associations between sites of aortic injuries and associated injuries were analyzed based on types of collision are shown in Table 5.

Table 5 The association between sites of aortic injuries and associated injuries

Association		***P*-value**
Sites of aortic injuries	**Associated injuries**	
Ascending (59/32.8%)	Fracture of sternum (30/50.8%)	.004
	Cardiac laceration (31/52.5%)	.001
Isthmus (87/48.3%)	Fracture of sternum (37/42.5%)	.005
	Cardiac laceration (35/40.2%)	.001
	Pelvic fracture (19/21.8%)	.030
Descending (7/3.9%)	Thoracic spine fracture (5/71.4%)	.001
Arch of aorta (15/8.3%)	No association found	> .05
Two sites (12/6.7%)	Pelvic fracture (5/41.7%)	.04

When the comparisons between sites of aortic injuries and anthropological parameters were analyzed by the Mann-Whitney U test, it was found that only patients with descending aortic injuries had significantly older age than patients without descending aortic injuries (44.30 ± 13.79 years old vs 33.66 ± 13.04 years old, P = .014). However, there was no significant difference between the other three sites of aortic injuries and other anthropological parameters.

Discussion

This study revealed that aortic injuries in motorcycle riders were mainly found in frontal collisions and this finding was consistent with several previous studies.[4-6,13,23] When sites of aortic injuries were considered, this study demonstrated that the isthmus was the most common site in BTAI for all types of collision. This finding was consistent with previous postmortem studies.[4-6,13,24] Interestingly, the second most common site was ascending aorta and the proportion of ascending aortic injuries in this study was relatively higher compared with previous studies especially in frontal collisions.[4-6,13,24] This finding was also contrast with the previous study in Thailand which indicated the proportion of ascending aortic injury at 15.4%.[16] This finding might result from the characteristics of recruited population because this study contained the proportion of frontal collision at 84.4%, whereas the previous study had the proportion of frontal collision at 41%. In addition, this study showed that ascending aortic injuries were significantly associated with frontal collisions whereas there was not any significant association between the other three aortic injuries and types of collision. Thus, this higher rate of ascending aortic injury was hypothesized to be associated with a frontal collision. It implied that the mechanism of ascending aortic injury should be closely related to frontal impact.

The most common sites of aortic injuries were approximately 1 cm above the sino-tubular junction for ascending aortic injury and 1 cm distal to the left subclavian artery for isthmus injury. The previous study suggested that the common sites of injuries for ascending aorta were near the origin of the brachiocephalic trunk followed by the proximal portion of the ascending aorta.[25] However, this study showed that the average position of ascending aortic injury was approximately 1 cm above the sino-tubular junction which was the proximal portion of ascending aorta. This finding was consistent with the study by Pelletti G et al., which stated that motorcycle riders in their study who had got ascending aortic injuries suffered from injuries at the proximal part of ascending aorta.[13] Further study should be conducted for elucidating this finding. When injury to the aortic isthmus was considered, it was found that the average distance of injury was 1 cm distal to the left subclavian artery and this finding was consistent with the previous study.[5,26] This finding was also corresponding with previous studies that demonstrated the maximal stress and strain at just distal to left subclavian artery when impact injury occurred.[11,12]

The most common associated injuries in BTAI in this study were liver laceration, head injury and rib fractures. This finding was consistent with previous studies.[5,7,24] Teixeira PG et al., also reported that diaphragmatic injury was significantly associated with BTAI.[7] However, this study did not include diaphragmatic injury in the data record because of some data missing in autopsy reports. Thus, further study should be performed to include more extensive data to define other associated injuries in BTAI. In addition, a frontal collision was significantly associated with a cardiac laceration in this study compared with a non-frontal collision. This finding was partly corresponding with the report from Teixeira PG et al., stating that cardiac injury was associated with BTAI.[7] This finding emphasized that the mechanism of BTAI in motorcycle riders in this study was associated with chest compression.

When the associations between aortic injuries and associated injuries were figured out, it was found that both injuries to ascending aorta and isthmus were associated with fracture of the sternum and cardiac laceration which implied that BTAI was closely correlated with chest compression. The sternal fracture was found strongly associated with BTAI in several previous studies.[5,6,16] In addition, injury to the aortic isthmus was also significantly associated with pelvic fracture. This finding implied that BTAI particularly at the isthmus might be related to high-velocity impact (which was related to high-force impact). For injuries to the arch of aorta, it was found that there was no significant association with any associated injuries in this study. Further research should be conducted to elucidate the associated mechanism of the arch of aorta injury. Interestingly, descending aortic injuries were associated with thoracic spine fracture in this study. Direct injury from thoracic spine fracture or indirect mechanism from fracture like hyperextension or bone displacement that affected tensile strength of the aortic wall might partly be associated with descending aortic injuries. In addition, this study showed that descending aortic injuries were also related to older age which was corresponding with previous studies indicating that the rate of overall TBAI in car occupants increased in older age.[4,23] However, as older age was also associated with increased atherosclerosis particularly after 40 years old[27] and related to vascular integrity, this effect might also be involved in descending aortic injuries. This finding should be clarified in the further work.

This study had some limitations. Firstly, this study had disproportionate ratio between frontal and non-frontal collisions, and this number led to some limitations in statistical analysis. Secondly, some sites of aortic injuries presented with a small number like arch of aorta and descending aorta. Thus, interpretation should be carefully performed and further large scale study should be conducted to obtain a greater number of less common sites of aortic injuries to achieve wider and deeper interpretations. In addition, most previous studies conducted research on mixed types of traffic accidents such as car drivers, pedestrians, and motorcycle crashes whereas this study concentrated on only motorcycle riders. Thus, some different comparison outcomes should be carefully interpreted due to different populations. Lastly, associated injuries were recorded only for major injuries that could be identified in autopsy reports. Thus, some injuries were not included in this study such as diaphragmatic injury and mesenteric injury. Consideration of this limitation may be necessary in further research.

In conclusion, injuries to isthmus followed by ascending aorta were the two most common aortic injuries found in motorcycle riders in Thai postmortem cases. These two sites of aortic injuries were also significantly associated with the fracture of sternum and cardiac laceration which implied the mechanism of chest compression. These study findings will help the interpretation of mechanisms of the injuries of motorcycle riders when they have aortic injuries and associated injuries. This will assist the police investigation in traffic crashes.

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Conflict of interest

All authors report no conflicts of interest relevant to this article.

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