Puncturing a castle defence: injury biomechanics solution to a homicide investigation case study

Geoffrey Thor Desmoulin*,
Mark-André Nolette and Kevin Bird

GTD Scientific Inc.,
2037 MacKay Ave,
North Vancouver, BC, V7P 2M8, Canada
Email: gtdesmoulin@gtdscientific.com
Email: manolette@gtdscientific.com
Email: kgbird@gtdscientific.com
*Corresponding author

Abstract: In the wake of a homicide, investigators were confronted with a castle doctrine self-defence argument that was difficult to refute with the tools and evidence at their immediate disposal. However, in his confession, the suspect claimed to have caused the stab wounds in an unusual manner. The victim's autopsy revealed that one of the stab wounds pierced the sternum and cut into the victim's heart, while another cut between ribs and stopped only at the knife hilt, causing a rib fracture. To provide insight into the likelihood of the suspect's narrative, investigators turned to injury biomechanics. It was possible to show the suspect's version of events had a low to an impossible bchance of occurring through quantitative testing relating to sternum stabbing, rib fracture load, and ergonomic analysis, ultimately leading to a change in plea to 3rd-degree murder. This case illustrates the worth of injury biomechanics when dealing with complex homicides and why the standard investigative toolbox should include it.

Keywords: injury biomechanics; homicide; stabbing; ergonomics; forensics.

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Biographical notes: Geoffrey Thor Desmoulin, PhD, RKin, PLEng, is the Principal of GTD Scientific Inc. (www.gtdscientific.com). GTD is an internationally recognised forensic engineering firm with focused practice areas in injury biomechanics, incident reconstruction and the Science of Violence®. GTD has been retained in significant complex injury litigation cases that involve Police Department use-of-force, homicide investigations, TASER International, and catastrophic vehicle collisions, to name just a few examples. Furthermore, he developed landmark testing and shooting reconstruction methodology was recently upheld as reliable and admissible by the US Federal District Court for the 9th District of California.

Mark-André Nolette, MSc, is an Injury Biomechanist at GTD Scientific Inc. He received a Master's degree in Biomedical Physiology from Simon Fraser University in 2012 and a Bachelor's degree in Mechanical Engineering from Université de Sherbrooke in 2009.

Kevin Bird holds a degree in Materials Engineering from the University of British Columbia. He was an Associate Engineer at GTD Scientific Inc. (www.gtdscientific.com) at the time of this research.

1 Introduction

In the summer of 2016, a man's body was discovered in Luzerne County, PA, with four stab wounds through the chest, three of them lethal. A man came forward to claim responsibility under a seemingly plausible self-defence narrative under the castle doctrine. While investigators doubted the defendant's story, conventional investigative methods made his prosecution difficult. This publication focuses on the enhancement provided by Injury Biomechanics methods that lead to a change in plea to 3rd-degree murder.

The critical aspects of this case revolved around verifying the validity of the defendant's narrative. In his version of events, the defendant claimed to have been protecting himself when under attack while sleeping in the back of his pickup truck. The Castle Doctrine, valid in Pennsylvania, allows one to defend their home (or vehicle) against intruders with deadly force. The defendant's narrative stated that he reflexively thrust the two knives he held up into the intruder's chest in a "Superman-like fashion". The deceased's autopsy revealed that one of the stab wounds pierced the sternum while others penetrated the chest wall from various angles, and one fractured a rib.

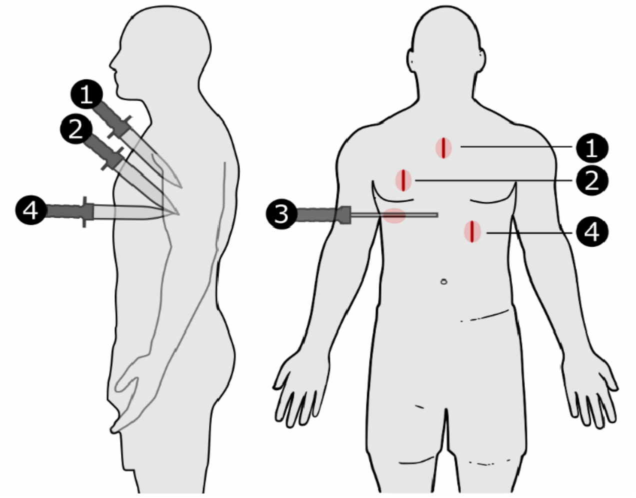
Considering the unusual nature of this narrative and the lack of information regarding stabbing tolerance of the sternum, measurements and biomechanical testing were performed to estimate the likelihood of an adult being able to puncture through the full thickness of a sternum in the orientation described. A human sternum analogue was constructed based on scientific literature and tested using a drop tower and a knife identical to the one used in the incident to produce the victim's injuries. The average stab force of adult males was measured in three different positions, including the one described in the suspect's narrative. An ergonomics analysis was performed to consider the body orientation and resulting wound paths. Finally, injury literature was consulted for rib fracture load.

2 Injury analysis

While the victim's body was found decomposed, four stab wounds could be identified, all located on his torso as depicted in Figure 1. Three of the four stab wounds were also estimated to be lethal and the cause of death.

Each stab wound identified in Figure 1 is detailed in the following paragraphs. It is important to note that the denotation #1 through #4 is from the autopsy report and only serves to identify the stab wounds and does not relate to the stab delivery's chronological order.

Figure 1 Approximate location of each puncture wound (see online version for colours)



Stab wound #1 is centred on the chest and perforates the sternum. The blade wound path is parallel to the sagittal plane and in the downward trajectory. The end of the stab is located in the heart's right ventricle as a 1-inch wide cut. The entry wound is 1.5 inches long. The entry wound is the same length as all stab wounds reported below.

Stab wound #2 is located on the right side of the chest, 4 inches from the midline. The stab is in the sagittal plane and is described as cutting through the 5th rib, left lung and liver, indicating a downward angled trajectory. The 4th rib of the same side is also fractured.

Stab wound #3 is also located on the right side of the chest, but more laterally than stab wound #2 at 5.5 inches to the right of the midline. Wound #3 is the sole incision that is not in the sagittal plane but instead in the transverse plane. The stab was described as going from right to left through the entire liver and cutting the 6th and 7th ribs in the process.

Stab wound #4 is the lowest of the four wounds and is located on the abdomen's left upper quadrant. It is located 2.5 inches from the midline and cuts the 8th rib. It is also described as penetrating the stomach, diaphragm, and left lower lobe of the lung. According to the coroner, stab wound #4 was oriented from front to back and horizontal or slightly downward.

Each of these stab wounds shows different information relative to each stab's orientation and magnitude. However, the force required to cause stab wound #1 indicates the effort put forth by the suspect. Although stab wounds #2 and #3 all partly cut through ribs to different degrees, stab wound #1 had to penetrate the sternum to reach the heart, and stab #4 cut completely through rib #8.

Information describing the force necessary to puncture the sternum with a knife could not be found in public literature at the time of this investigation. In contrast, information regarding rib fracture tolerance was found (McElhaney et al., 1976) and stab #2's associated fracture of rib #4 indicates associated blunt force trauma with the stab's execution.

3 Methods

3.1 Sternum stabbing force testing

The first test phase aimed to identify the sternum tolerance limit when faced with a knife attack; therefore, human data describing sternum structure was queried.

The sternum is a large flat bone, approximately 159 mm long by 66 mm wide (Lindner et al, 2017), which is part of the rib cage and protects the heart and lungs (Gladstone and Wakeley, 1932). The sternum thickness has been reported at approximately 15 mm but can be as thick as 21mm. The sternum thickness has also been described as 0.16 mm/kg of body weight (Zetani et al., 2006). In the case of the victim, assuming his weight was proportional to his height at the time of the incident (Peebles and Norris, 1998), his sternum's thickness can be estimated to be approximately 16 mm.

Each sternum sample was made of two different polyurethane foam layers (Pacific Research Labs Inc., Vashon Island, WA), a material that has been characterised as a model for human bone (Dasika et al., 2003; Szivek et al., 1993) and used to construct sternal models for medical studies (Trumble et al., 2002). Since a human sternum is comprised of cancellous bone encased in a thin layer of compact cortical bone (Lindner et al., 2017), the synthetic bone samples included a low density (20 lbs/ft^3) foam core with a thin layer of denser (50 lbs/ft^3) material on either side for a total thickness of 16 mm, which matched that of the deceased. The ratio of cortical to cancellous bone was determined based on orthopedic research as approximately fivefold. A ballistic soap block (Concordia P. Llave, West Covina, CA) of more than 8 inches was placed behind each synthetic bone sample to represent soft tissue.

Hence, a sternal model was located at the bottom of a drop tower where an exemplar knife was guided to the sample. The force of the impact was modulated using different start heights for the knife and measured using load cells (#208C05, PCB Piezotronics, Depew, NY) and a data acquisition system (NI cDAQ-9181 from National Instruments, Austin, TX). The knives used were the same make and model as the case knife seized from the suspect.

Drop height was designed to cover a range of penetration into the samples, from negligible to most of the blade which correlated to the range of force required to penetrate the sternum.

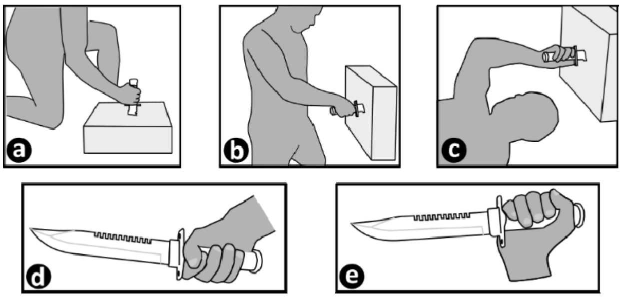
3.2 Stab force testing

The second test phase aimed to quantify the forces generated by an able-bodied man stabbing in different orientations. Two study participants were asked to stab a force plate three times in three different orientations. The forces were measured using the same data acquisition system previously outlined.

The following configurations were tested and can be seen in Figure 2:

- downward stab with reverse grip
- forward thrust with forward hammer grip
- supine overhead thrust with forward hammer grip.

Figure 2 (a) Downward thrust; (b) forward thrust; (c) overhead supine thrust; (d) forward hammer grip and (e) reverse grip



4 Results

4.1 Sternum tolerance results

The test performed using the drop stand and the synthetic bone samples yielded the relationship shown in Figures 3 and 4. The relationship illustrated in Figure 3 establishes a near-perfect fit ($R^2 = 0.9902$) and allows for interpolation of the penetration for different stab velocities using this specific test setup.

Figure 3 Knife penetration due to speed of impact (see online version for colours)

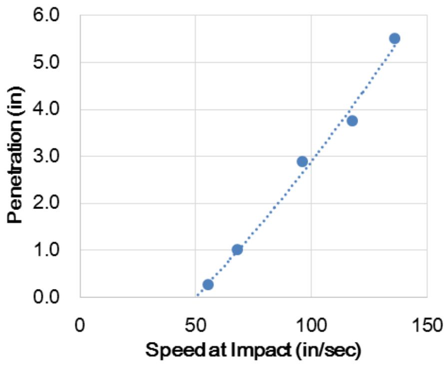
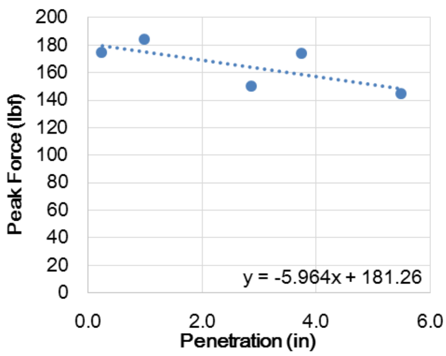


Figure 4 Sternum tolerance results (see online version for colours)



Using this relationship and the force data collected during testing (Figure 4), it is possible to estimate the sternum's force tolerance using the incident knife. At approximately 181 lbf the penetration would have been negligible. At any higher force, the sternum would have started failing, and the knife would have been able to start penetrating the body.

4.2 Stab force results

The summary of peak stab forces measured over three trials per subject for each orientation are shown in Table 1.

Table 1 Peak stab force results by orientation in pounds-force

	AVG	*STD*	*Min*	*Max*
Downward stab	755	155	598	1046
Forward stab	386	120	244	516
Overhead supine stab	201	46	147	274

The downward stab generates the largest force, followed by the forward thrust, with the supine overhead thrust generating the smallest force. The supine overhead stab only generated an average of 27% of the downward stab force while the forward stab produced 51%.

In addition, the fracture of rib #4 associated with stab #2 can be examined with regards to stabbing force. While loads necessary to cut through ribs could not be found in the literature, a relatively large body of data exists with respect to thoracic blunt trauma injuries, including rib fractures. While rib #5 was cut with the sharp side of the blade, it is likely that rib #4 fractured via blunt force from the combined impact of the hilt and fist. A research group (McElhaney et al, 1976) found that a 22-lb impactor centred on the space between the fourth and fifth rib, as the knife was during stab #2, did not cause rib fractures during multiple human post-mortem tests. The peak forces recorded during these tests were as high as approximately 1400 lbf. Since no rib fractures were discovered during the study's impact tests, it is assumed that under those conditions, rib fractures occur at either higher loads or under smaller surface areas. A small area would therefore result in a larger pressure at the point of impact.

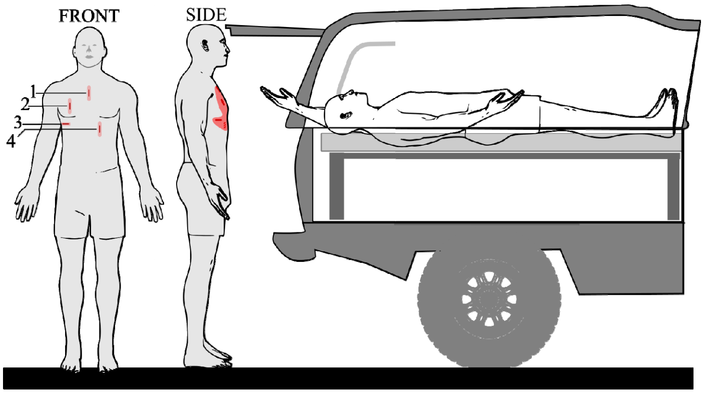
Based on the absence of fractures in this study, it is possible to estimate the force equivalent over a smaller impactor area. In the stabbing motion in question, the hand/hilt system can be estimated as having a diameter of 3 in, therefore the equivalent force in the hand/hilt system to the highest force recorded in the study would be approximately 350 lbf. This suggests that a supine overhead thrust, the technique the suspect claimed using, would be unable to produce the fracture in question.

5 Ergonomics analysis

Using the information available about the suspect, his vehicle and the victim, it was possible to analyse the incident from an ergonomics point of view.

It was possible to observe that the victim's injuries were generally placed at a height that coincided with the lower half of the truck canopy's rear window, as shown in Figure 5. The next step was to identify the ergonomic plausibility involved with the suspect producing the reported injuries from his position. To do so, the suspect's functional range of motion (Namdari et al., 2012) had to be calculated as well as his overall reach (Peebles and Norris, 1998) from within the vehicle.

Figure 5 Mock-up of incident showing a front view of the victim's injuries, and a side view including the suspect drawn to scale inside the back of his vehicle (see online version for colours)



First, the stab wound to the sternum (#1) and, a second, more lateral wound (#2) was investigated. Both wounds were described by the medical examiner as having a downward angle of penetration. In order for the suspect to inflict these wounds, the victim would have had to be leaning forward and under the canopy that he just raised, as the space available would not have allowed for a downward angle of approach. The suspect's testimony, however, clearly stated that he delivered his strikes immediately as the victim opened the canopy window. This, therefore, left little to no time for the victim to bend under the canopy in an orientation that would correspond with the injuries' angle. Further, the suspect denied on two separate questions that the victim ever reached inside the cab, and no evidence of blood was found inside the vehicle to support a theory that the suspect had been leaning into the vehicle. In addition, a dimensional analysis showed that the position of the victim in order to successfully open the canopy window would have put him outside of the range of the suspect.

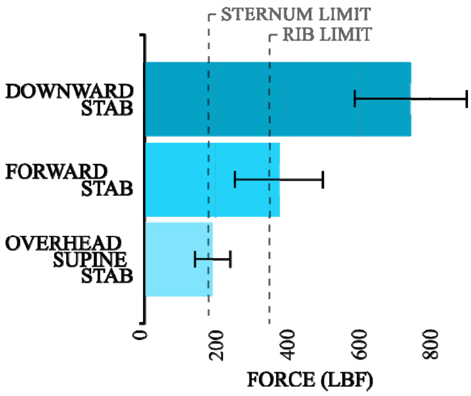
A third stab wound (#3) was found to have a notably different trajectory than the first two injuries previously discussed as the entry wound had a lateral to medial direction with a horizontal, rather than vertical blade orientation. Such a large divergence in the orientation of the blade and angle of penetration suggests a dynamic situation that either involves different types of strikes or changes in the relative position of the two men. This suggests two possibilities; either the suspect changed his angle of attack, or the position of the victim changed in relation to the suspect. Neither of those hypotheses was consistent with the self-defence narrative put forward by the suspect. The suspect's depiction of his strikes would suggest that all strikes had the same orientation and a similar angle of attack, which was not in agreement with findings.

Lastly, despite the suspect claiming to have attacked the victim with three knife thrusts, a fourth stab wound (4) was found on the front of the chest, low on the rib cage and two to three inches left of the midline. For the suspect to be able to produce this stab wound from his supine position, he would have had to have an angle of attack, which would put the blade at a markedly downward angle. However, this was not consistent with the damage to the victim's internal organs. The injuries suggest a more horizontal strike, which, again, would have been difficult if not impossible to produce from where the suspect claimed to have been positioned.

6 Discussion

Based on the information presented thus far, it was possible to examine the likelihood of the suspect being able to produce the injuries in question while being in a supine position. Using an injury biomechanics approach, the test results can be used to examine the link between the force generated in each stabbing position and the tolerance of the sternum (Figure 6).

Figure 6 Tolerance of sternum model to different stabbing approaches (see online version for colours)



As previously mentioned, results showed that the case knife had the ability to penetrate the sternum under loads of 181 lbf or greater.

It was also shown that it is possible, with different degrees of difficulty, for some adult males to produce enough force to stab through a human sternum in all three tested positions. A downward stab or forward thrust, for example, can generate 4.2 and 2.1 times, respectively, the stabbing tolerance force of the sternum (181 lbf). However, the overhead supine stabbing force did not exceed the same tolerance with such margin. In fact, the magnitude of the force generated is reduced by almost 500 lbf, making sternal penetration much more difficult and less likely. Therefore, although physically possible, the degree of difficulty involved in stabbing through the sternum in this position would be much higher than in other more physically dominant orientations.

Further, independent data using post mortem cadavers and the identification of rib fractures showed that the overhead supine stabbing force was insufficient to cause the documented injury. When matching for identical impact pressures across the study impactor and that available to the suspect, it is apparent that the overhead supine stab was unable to create the fracture of the fourth rib associated with stab #2. This corroborates the idea that the suspect could not have caused the documented injuries from the supine overhead position.

Also, while confined to the back of his vehicle, the suspect would have been working at the end of his shoulder flexion range of motion in order to reach the victim. A study by Mayer et al. (1994) measured the angle of peak torque for various shoulder movements (Mayer et al., 1994). The study found that for concentric flexion movements, which describe the supine overhead stabs, the suspect would have been stabbing far beyond his peak flexion angle and functional range of motion. Alternatively, in an upright position, the suspect would not have had the same restrictions and would have been able to generate the appropriate torque.

Considered as a whole, the data determined that it was 'beyond a reasonable doubt' or in statistical terms 95% confident that at least one of the lethal knife thrusts (stab #2) was generated outside of the truck bed and therefore the castle defence theory.

Limitations of the experimental approaches used to conduct the injury analysis of the sternum penetrating stab wound include that the similarity of the experimental model to a real living human is largely unknown. The sternum model was constructed using the victims' physical proportions and validated materials found in the literature however factors such as age and health (Weaver et al., 2014) of an individual can significantly affect the fracture force of ribs affecting the accuracy of the sternum model and hence the results gathered.

The other main weakness of the approach is that the physical strength of the suspect compared to the subjects who participated in the study is unknown, and assumptions are made that the suspects' stabbing strength is on par or better than the performance of the subjects who participated in the testing. However, this was a conservative estimate considering the backgrounds of the participants, namely one of them having years of resistance training in overhead movements due to being a trained weightlifting athlete and thus was able to produce a higher peak force in the supine position. While the other participant was not able to generate enough force to pierce the sternum model with an overhead supine stab. This reinforced the conclusion that an overhead supine stabbing by the suspect was likely not able to generate the force required to pierce the sternum compared to stabbings in alternative positions. Lastly the results indicated that there were other more plausible scenarios where the force would be easier to generate to be able to cause four different stab wounds with three different orientations.

7 Conclusion

In concert with the original investigation performed by detectives, the analysis provided strong evidence against the suspect's narrative. Using the wound paths provided in the autopsy report, the suspect's narrative was tested as a hypothesis. Due to the lack of relevant information regarding sternum penetration in literature, the sternum tolerance and stab force tests were designed to determine the amount of force and effort required to penetrate the sternum in different positions. This additional injury biomechanics work along with the ergonomic analysis conducted determined the likelihood of creating the wound paths seen in the autopsy reports in the manner described by the defendant.

This contributed to the defendant changing their plea from self-defence to guilty on 3rd-degree murder charges. Sentencing was immediate, and it is believed the contribution of injury biomechanics assisted in bringing an end to a difficult conviction.

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