

**VARIATION IN THORACIC WALL THICKNESS ON  
MULTI-DETECTOR CT IN ADULT PATIENTS AND ITS  
IMPLICATIONS IN NEEDLE THORACOSTOMY FOR  
TENSION PNEUMOTHORAX.**

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## DECLARATION

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## List of abbreviations

AAL: Anterior Axillary Line

ATLS: Advanced Trauma Life Support

BMI: Body Mass Index

CT: Computed tomography

GSH: Groote Schuur Hospital

ICS: Intercostal Space

ITLS: International Trauma Life Support

MAL: Mid-axillary Line

MCL: Midclavicular Line

PACS: Picture Archiving and Communication System

SPSS: Statistical Package for the Social Sciences

# **CHAPTER 1: LITERATURE REVIEW**

## **Introduction**

Trauma is one of the main causes of death, with chest trauma accounting for up to 25 % of deaths worldwide<sup>1</sup>. This is particularly concerning in low socioeconomic countries<sup>1</sup>. For over two decades, blunt and penetrating trauma in South Africa have been recognised as an epidemic<sup>2</sup>, due to the high rates of violence in this country. The data from “Mortality and causes of death in South Africa” published in 2017, stated that non-natural causes of deaths accounted for up to 11.7% of all deaths, including assaults and transport accidents<sup>3</sup>. Morbidity and mortality are highly linked to the presence and severity of blunt and penetrating chest trauma<sup>1</sup>. Tension pneumothorax is one of the immediate life-threatening complications of chest trauma. If it is not managed appropriately and promptly in a pre-hospital setting, this may result in death of the patient<sup>1</sup>.

Due to recent realization of varied chest wall thickness, the aim of the study is to evaluate the average chest wall thickness in South African patients, presenting to the Groote Schuur Hospital Trauma Unit in the Western Cape, and to assess alternative sites for needle decompression in trauma patients.

## **Chest wall anatomy**

An essential part of the human ventilatory pump is the chest wall<sup>4</sup>, which is located in the upper portion of the torso, extending from the neck to the upper abdomen, with a reniform shape in all views. From the exterior to the interior, the thoracic wall comprises the skin, followed by subcutaneous tissue and mammary glands, the neurovascular bundle, the superficial and deep chest wall muscles and osseocartilaginous thoracic cage<sup>5</sup>. Beneath the thoracic cage, lies the extra pleural space, which extends between the inner rib surface to the parietal pleura<sup>6</sup>. The parietal pleura is the outer layer of the pleural cavity, whilst the most inner layer is the visceral pleura, with a sliver of pleural fluid between the two pleura<sup>7</sup>. The visceral pleura lines the important structures, namely the lungs, heart and mediastinal structures<sup>7</sup>.

## **Factors influencing chest wall thickness**

Many pathologies may occur in the chest wall, which influences its thickness. These pathologies can be classified according to the layers of the chest wall<sup>8</sup>. Common pathologies such as infection, benign and malignant tumours will increase the chest wall thickness depending on the extent of the disease<sup>8</sup>. Several studies have shown that obesity and gender (i.e. females) are additional risk factors contributing to chest wall thickness<sup>9</sup>. Furthermore, chest wall trauma may cause bleeding into the extra pleural space, thus forming hematoma surgical emphysema can lead to increased chest wall thickness. Lastly, athletes that focus on upper body training increase their pectoralis muscles, adding to the chest wall thickness<sup>10</sup>.

## **Aetiology of pneumothorax**

The causes of pneumothorax can be classified into traumatic, iatrogenic or spontaneous.<sup>11</sup> Traumatic pneumothorax is caused by a pierced chest wall and lung, such as from a stab or gunshot wound, or rib fractures.<sup>12</sup> Pneumothorax is a common complication arising from some diagnostic or therapeutic interventions<sup>13</sup> such as positive-pressure ventilation, attempted central line insertions, lung lesion biopsies and surgical procedures in the upper torso.<sup>14</sup> In addition, pneumo-retroperitoneum from abdominal surgery (such as iatrogenic perforation of the colon during colonoscopy) may also track into the thorax.<sup>14</sup>

The term spontaneous pneumothorax (SP) is used if pneumothorax is not trauma- or procedure-related<sup>11,12</sup>, and is further sub-classified to primary SP (PSP) or secondary SP (SSP)<sup>11</sup>. PSP is defined as SP without an underlying lung disease, whereas SSP has an underlying lung disease.<sup>11</sup> PSP has a peak incidence at 35 years of age, more common in smokers, tall and thin individuals and with a family history of SP.<sup>15</sup> The primary cause for SSP is chronic obstructive pulmonary disease with emphysema. Other causes include tuberculosis, necrotizing pneumonia, cystic fibrosis, interstitial pneumonitis, lung cancer and Human Immunodeficiency related pneumocystis carinii pneumonia<sup>11,12,15</sup>. Genetic syndromes may also play a role in SSP, particularly those related to tumour-suppressor genes (such as pulmonary lymphangioleiomyomatosis, or Birt-Hogg-Dube syndrome) or to connective tissue diseases (such as Ehlers-Danlos Syndrome and Marfans Syndrome)<sup>15</sup>.

## **Pathophysiology of tension pneumothorax**

When a patient sustains either penetrating or blunt thoracic trauma, or both, there is an increased risk of acquiring one of three serious conditions with high morbidity and mortality rates<sup>16</sup>. These conditions are open pneumothorax, haemothorax and tension pneumothorax<sup>16</sup>. These result in air, blood, or both accumulating within the pleural cavity that encases the lungs and mediastinal structures, including the heart. As this study is focused on tension pneumothorax, the other two conditions will not be discussed in detail.

Tension pneumothorax usually occurs when there is an underlying lung, bronchial, or tracheal injury acting as a one-way flap valve. During inspiration, persistent air leaks into the pleural space without a route to escape on expiration<sup>16, 17</sup>. If this trapped air exceeds a certain volume or pressure, the underlying lung parenchyma will be severely compressed, and the cardio-mediastinal structures will shift to the contralateral side. The persistent pulmonary shunting and lung parenchymal collapse will lead to hypoxia, progressive respiratory failure, cardiovascular collapse and ultimately death if not managed promptly.

## **Clinical diagnosis of tension pneumothorax**

The clinicians should suspect underlying traumatic chest injury in all patients who have sustained acute and severe thoraco-abdominal injury, Tension pneumothorax is one of the major complications which requires immediate management in a pre-hospital setting.

Signs of significant chest trauma include rib fractures, skin abrasions, penetrating wounds or surgical emphysema<sup>16</sup>. Patients are likely to present with pain, progressive dyspnoea, and asymmetrical chest movement with respiration<sup>16</sup>. Hypoxia and tachycardia, as well as decreased breath sounds and hyper-resonance on percussion are clinical signs of an underlying pneumothorax, which may be complicated by tension<sup>1</sup>. Rare findings such as jugular vein distension and tracheal deviation, may suggest imminent circulatory collapse<sup>16</sup>. It is therefore important to perform life-saving needle decompression to temporarily alleviate the tension pneumothorax in a pre-hospital setting<sup>1</sup>. Tube thoracostomy can be performed once the patient has reached the hospital trauma centre.

## **Radiological diagnosis of pneumothorax**

The presence of pneumothorax can be confirmed via different imaging modalities, such as radiography, ultrasound or computed tomography (CT)<sup>13,18,19</sup>. Diagnosing pneumothorax on a chest radiograph is dependent on the position of the patient, either erect or supine<sup>13</sup>. If a patient is in the erect position, free air can be seen in the apex of the lung as a visceral pleural line, with the absence of peripheral lung markings<sup>18</sup>. If in supine position, the common locations to seek free air is in the juxta cardiac area, lateral chest wall and subpulmonic area<sup>13</sup>. However, a deep costophrenic angle, known as the deep sulcus sign, may be the only finding<sup>13</sup>. For equivocal cases, lateral decubitus views are recommended<sup>18</sup>. Tension pneumothorax must be suspected if there is a large pneumothorax with contralateral mediastinal shift, ipsilateral rib cage expansion and diaphragmatic depression<sup>13</sup>.

On ultrasound, a pneumothorax appears as an hypoechoic area in relation to the underlying echogenic lung, and up to ten sonographic signs can be seen to confirm this<sup>19,20</sup>. Some of these signs include the bat sign, the A-line sign, lung sliding sign, the quad sign, etc<sup>20</sup>.

Apart from confirming pneumothoraces in unequivocal cases, CT can also identify the underlying causes of SSP such as emphysema, blebs and lymphangioleiomyomatosis. Another advantage of CT is that it can distinguish pneumothorax from a large lung cyst or bullous disease, which are great mimickers of pneumothorax<sup>13,18</sup>.

## **Current management guidelines**

The traditional management of tension pneumothorax has been needle thoracocentesis, using a 14 gauge 50mm long large-calibre angiocatheter, inserted in the 2<sup>nd</sup> intercostal space in midclavicular line<sup>21</sup>. However, due to variations in chest wall thickness and the low success rate of reaching the pleural surface at this level, the guideline was revised in the Advanced Trauma Life Support 10<sup>th</sup> edition (2018) stipulating that the preferred site for needle decompression was the 5<sup>th</sup> intercostal space in the anterior axillary line for adults<sup>22</sup>. Furthermore, the 7<sup>th</sup> edition of the International Trauma Life Support (ITLS) Provider manual has suggested additional locations where needle decompression can be performed<sup>23</sup>. The current 8<sup>th</sup> edition recommends both anterior and lateral approaches, with their own

advantages and disadvantages<sup>24</sup>. In the United Kingdom, The Royal College of Surgeons of Edinburgh has suggested the initial attempt for needle decompression to be performed in second intercostal space, midclavicular line. However, if no clinical improvement is observed, needle decompression should be re-attempted in the 5th intercostal space, anterior to mid axillary line<sup>25</sup>.

### **Current literature review**

Using the guidelines provided for tension pneumothorax management, several studies have shown that the 50 mm needle catheter length was not sufficient for needle decompression via the traditional 2nd intercostal space, midclavicular line. In a Turkish population study, the 50 mm catheters did not reach the pleural space in 33% of the female and over 10% of the male populations, regardless of puncture site. However, if needle decompression was necessary, the authors suggested the optimal puncture site was the 5th intercostal space in the mid-axillary line<sup>26</sup>. Another study, measuring chest wall thickness in two anatomical locations (2nd ICS in midclavicular line and 5th ICS in anterior axillary line), concluded that the 45 mm catheter was too short for needle thoracostomy, regardless of puncture site or gender in most patients<sup>27</sup>.

Several studies have suggested that longer needles are required for the management of tension pneumothorax<sup>25,28–30</sup>. Theodore et al. (2007) assessed the chest wall thickness in military personnel and confirmed that 50mm angiocatheter would have only reached the pleural space in just over 50% of their subjects, while an 8cm angiocatheter could reach the pleural space in 99% of the cases<sup>28</sup>. There is a high failure rate of needle decompression in trauma patients, as the depth of injured chest wall is thicker compared to uninjured chest wall<sup>31</sup>. It was also found that there is a 42% risk of iatrogenic cardiac injury using an 8cm angiocatheter in the 5<sup>th</sup> intercostal anterior axillary line<sup>31</sup>. Furthermore, needle decompression in tension pneumothorax in Asian trauma patients are more likely to succeed via the lateral approach or with a longer angiocatheter. High body mass index (BMI) is a high predictor of failure, especially via the anterior approach<sup>30</sup>. In addition, tube thoracostomy should be considered in pre-hospital settings<sup>29</sup>.

However, Chanthawatthanarak et al. (2019) showed that in Thailand, the chest wall thickness was greater at the anterior axillary line in the 5<sup>th</sup> intercostal space, compared the mid-clavicular line in the 2<sup>nd</sup> intercostal space.<sup>32</sup> This was confirmed in a recent multicentric prospective study performed in the Netherlands which assessed the success rate of needle decompression in correlation with BMI status at the prescribed regions. The authors found that in patients with high BMI, the chest wall thickness via the lateral approach (4<sup>th</sup> and 5<sup>th</sup> intercostal spaces, anterior axillary line) was thicker in comparison to the traditional anterior approach (2<sup>nd</sup> intercostal space, midclavicular line). This suggested that the success rate for needle decompression is markedly higher in 2<sup>nd</sup> intercostal space, rather than the newly prescribed 4<sup>th</sup>/5<sup>th</sup> intercostal spaces<sup>33</sup>.

### **Aim of the study**

It is evident from the published studies that chest wall thickness varies in countries and is highly correlated to BMI scores. To our knowledge, no studies evaluating the chest wall thickness have been published in the South African population. Thus, this study aimed to evaluate the average chest wall thickness in South African patients, presenting to the Groote Schuur Hospital Trauma Unit in the Western Cape, and assessed alternative sites for needle decompression in trauma patients.

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## **CHAPTER 2: FULL TEXT JOURNAL ARTICLE FOR SUBMISSION.**

### **VARIATION IN THORACIC WALL THICKNESS ON MULTI-DETECTOR CT IN ADULT PATIENTS AND ITS IMPLICATIONS IN NEEDLE THORACOSTOMY FOR TENSION PNEUMOTHORAX.**

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#### **Abstract**

**Background:** Traditional treatment guideline for chest trauma to prevent tension pneumothorax is needle thoracostomy with a large-calibre catheter needle inserted in the second intercostal space (ICS) in the midclavicular line (MCL). However, due to variations of chest wall thickness, the 50 mm needle-mounted catheter is insufficient and may only reach the pleural space.

**Objectives:** To investigate whether the recommended anatomical site and the length of the angio-catheter used for patients in Western Cape, South Africa was optimal and explore alternative locations.

**Methods:** We performed retrospective study measuring chest wall thickness of adult patients treated for chest injuries in the Grootte Schuur Hospital (GSH) trauma unit between 2014 and 2016. These patients underwent contrasted CT chest studies and image data were obtained via GSH Picture Archiving and Communication System. Multiple levels and sites of CWT were measured, using multiplanar CT acquisition. Patients with underlying chest wall pathology that is not trauma related, congenital anatomical abnormality, foreign bodies or partially imaged chest were excluded.

**Result:** A total of 153 patients were eligible for the study. The mean  $\pm$  SD chest wall thicknesses of the left and right 2nd ICS MCL were  $41,03 \pm 15,24$  mm and  $41,77 \pm 15,83$  mm, respectively. Thus, suggesting that 20.9% of patients (n=32) would fail needle decompression at 2nd ICS MCL. The average CWT of the 3rd ICS MCL, 4th ICS MCL, 4th ICS AAL, 4th ICS MAL, 5th ICS MCL, 5th ICS AAL, 5th ICS MAL were 33.95, 27.18, 34.41, 41.31, 21.68, 28.42 and 36.31mm, respectively.

The location with the highest needle decompression failure rate was the right 4th ICS MAL (26.1%), whereas the lowest failure rate was the right 5th ICS MCL (3.9%). The location with the highest rate of organ injury was the 4th ICS MCL (26%), and the safest location was at the 4th ICS MAL with no organ injury.

**Conclusion:** Failure rate for needle decompression using the traditional 14G 50 mm angiocatheter at the 2nd ICS MCL in the South African population is high. We recommend that needle decompression should be performed at the 5th ICS AAL, due to the low failure rate and reduced risk of iatrogenic organ injury.

## Introduction

For over two decades, both blunt and penetrating trauma in South Africa have been recognised as epidemics.<sup>1</sup> Morbidity and mortality are highly correlated with the presence and severity of blunt and penetrating chest trauma. One of the immediate life-threatening complications of chest trauma is a tension pneumothorax, caused by a laceration of the lung, with a flap-valve leading to increased pleural pressure.<sup>2</sup> This results in contralateral shift of the mediastinum associated with compromised ventilation and cardiac function, leading to respiratory distress and/ or hypotension.<sup>3</sup>

In tension or large pneumothorax, the traditional Advanced Trauma Life Support (ATLS) guidelines recommend needle thoracostomy with a large-calibre catheter needle inserted in the 2<sup>nd</sup> intercostal space (ICS), just superior to the 3<sup>rd</sup> rib in the midclavicular line (MCL) as the initial treatment.<sup>4</sup> The 10<sup>th</sup> edition of the ATLS guidelines (2018)<sup>5</sup> advises that for adults the preferred space for needle decompression is the 5<sup>th</sup> ICS in the anterior axillary line.<sup>5</sup> The 7<sup>th</sup> edition of International Trauma Life Support (ITLS) Provider Manual suggested additional locations where needle decompression can be performed.<sup>6</sup> However, the current ITLS 8<sup>th</sup> edition recommends both anterior and lateral approaches, each with advantages and disadvantages.<sup>7</sup> In the United Kingdom, The Royal College of Surgeons of Edinburgh suggests the initial attempt for needle decompression should be performed in the 2<sup>nd</sup> ICS MCL. However, if no clinical improvement is observed, needle decompression should be re-attempted in the 5<sup>th</sup> ICS in the anterior axillary line (AAL).<sup>8</sup> In addition, tube thoracostomy should be considered in pre-hospital settings.<sup>14</sup>

Due to variations of chest wall thickness, the traditional 50 mm long 14 gauge angiocatheter may only reach the pleural space approximately 50% of the time.<sup>4</sup> Several studies have shown that the traditional 50 mm needle catheter length was too short for needle decompression via the 2<sup>nd</sup> ICS in many patients. In a Turkish study, 50 mm catheters did not reach the pleural space in 33% of female and over 10% of male participants, regardless of the puncture site. However, if needle decompression was essential, the best puncture site was felt to be the 5<sup>th</sup> ICS in the mid-axillary line (MAL).<sup>9</sup> In another study of chest wall thickness measured in two anatomical locations (2<sup>nd</sup> ICS MCL and 5<sup>th</sup> ICS AAL), it was concluded that the 50 mm angiocatheter was too short for most needle thoracostomies, regardless of puncture site or

gender in most patients.<sup>10</sup> Theodore *et al.* (2007) assessed chest wall thickness in military personnel and confirmed that the 50 mm angiocatheter would reach the pleural space in over 50% of their participants, while an 80 mm angiocatheter would reach the pleural space in 99% of cases.<sup>11</sup> Needle decompression in tension pneumothorax in Asian trauma patients is more likely to succeed via the lateral approach or with a longer angiocatheter. Chanthawatthanarak *et al.* (2019) showed that in Thailand their patients' chest wall thickness was greater at the 5<sup>th</sup> ICS AAL, compared to the 2<sup>nd</sup> ICS MCL.<sup>15</sup>

High body mass index (BMI) is a high predictor of failure, especially via the anterior approach.<sup>13</sup> A recent multicentric prospective study performed in the Netherlands assessed the success rate of needle decompression in correlation with BMI at the prescribed regions. The authors found that in patients with high BMI, the lateral chest wall (4<sup>th</sup> and 5<sup>th</sup> ICS AAL) was thicker in comparison to the traditional anterior approach (2<sup>nd</sup> ICS MCL). This suggested that the success rate for needle decompression should be markedly higher in the 2<sup>nd</sup> ICS, rather than the 4<sup>th</sup>/5<sup>th</sup> ICS.<sup>16</sup>

There is also a high failure rate of needle decompression in trauma patients, as the depth of injured chest wall is often thicker compared to the uninjured chest wall.<sup>12</sup> Furthermore, there is a 42% risk of iatrogenic cardiac injury using an 80 mm angiocatheter at the 5<sup>th</sup> ICS AAL.<sup>12</sup>

South Africa is a multicultural developing country with different diets and lifestyles which may contribute to changes in body habitus, resulting in variable chest wall thicknesses. This study aimed to evaluate the average chest wall thickness at specified sites in South African patients presenting to the Groote Schuur Hospital (GSH) Trauma Unit in the Western Cape. It also assessed alternative sites for needle decompression in trauma patients.

## **Methods**

### **Participant sampling criteria**

This retrospective study was performed at GSH, a tertiary institution in the Western Cape, with a high intake of trauma patients daily. Patients were selected using a stratified random sampling method according to age. 200 patients between 18 and 80 years-old, presenting to the GSH trauma unit with upper torso injury between January 2014 to December 2016 were

included in the study. Common trauma-related chest wall pathologies such as surgical emphysema and soft tissue hematoma were included and documented in the study as these associated pathologies needed to be traversed to reach the pleura. Exclusion criteria included patients with known underlying chest wall, rib, or pleural disease (e.g., malignancy), congenital anatomical abnormality, those with foreign bodies in the region of interest, and partially imaged chests.

### **Chest wall measurements**

Patients with penetrating or blunt trauma, or both, underwent CT if underlying lung or vascular injury were clinically suspected. Contrast chest CT studies were performed as per CT protocol using either the Toshiba Prime 160 slice or the Siemens Emotions 16 slice scanner.

Chest wall thickness was measured in the 2<sup>nd</sup> ICS (MCL), 3<sup>rd</sup> ICS (MCL), 4<sup>th</sup> ICS (MCL, AAL, MAL), and 5<sup>th</sup> ICS (MCL, AAL, MAL) bilaterally. The clavicular length on the frontal scout image was measured and 50% of the length of the clavicle was used to determine the MCL. Then on the axial CT images, the MCL distance was measured from the sternoclavicular joint. A line was then drawn from the skin surface perpendicular to the pleura in the intercostal space, at a level just superior to the lower rib.<sup>9</sup> (Fig 1a)

For the AAL, the relevant ICS was identified on the axial images. AAL is located just lateral to the pectoralis major muscle. At this level, a perpendicular line was then drawn from the skin surface to pleura.<sup>17</sup> ( Fig 1b)

To measure the MAL in the same coronal plane as the axilla, a line was drawn from the skin surface perpendicular to the pleura in the ICS.<sup>9</sup> ( Fig 1c)

Fig 1a: measurement of chest wall thickness at MCL

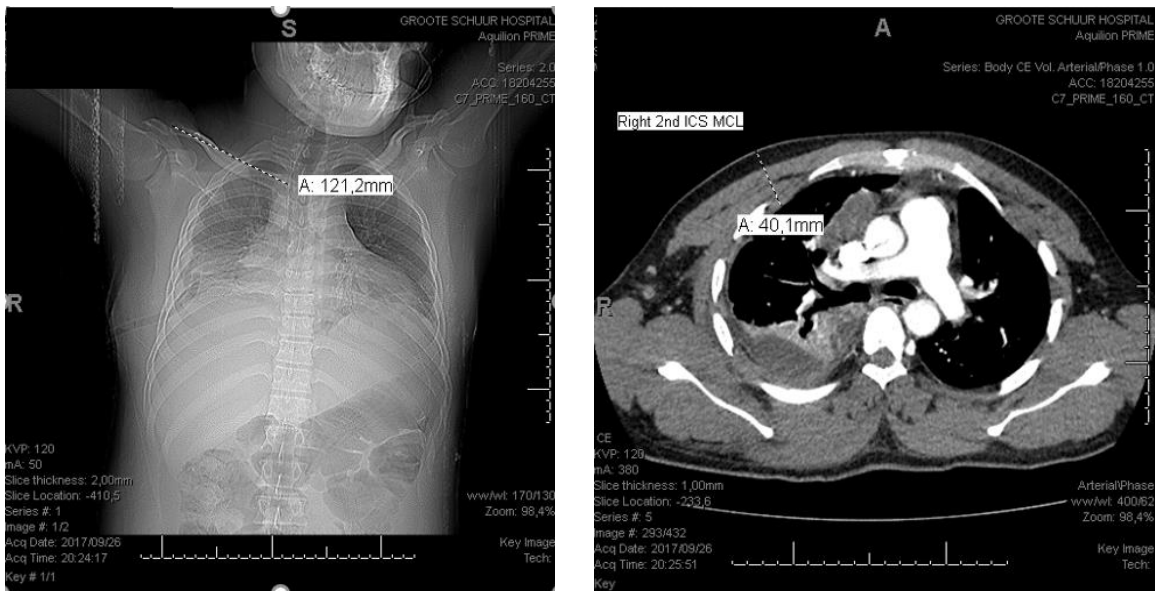
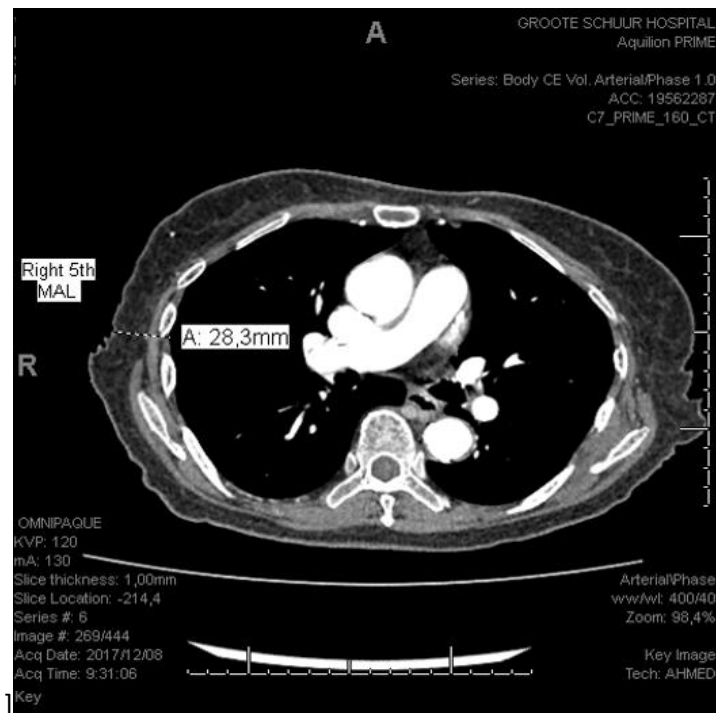


Fig 1b: Measurement of chest wall thickness at AAL



Fig 1c: measurement of chest wall thickness at MAL



## Data analysis

Statistical analysis was done using the Statistical Package for the Social Sciences (SPSS), version 27. Descriptive statistics were in the form of frequency tables and summary statistics. Student's t-test was used to compare various chest wall thicknesses. A p-value less than 0.05 was considered significant. Data were reported as means  $\pm$  Standard Deviations.

## Ethical considerations

This study was approved by the University of Cape Town Faculty of Health Sciences Human Research Ethics Committee (HREC number: 717/2018) and the Groote Schuur Hospital Institutional committee. All data was collected using the GSH Picture Archiving and Communication System (PACS). Patients' details were anonymised and only the study numbers were used as identifiers. All collected data was stored in a password-protected computer.

## Results

### Demographics:

Data from 200 patients were collected, however, only 153 patients fit the inclusion criteria, of which 83% were male patients (Figure 2a). Most of the excluded patients (n=38) were due to images not scanned within the field of view. The mean age of patients was 33 years,  $10 \pm 11,26$  ranging from 18 to 82 (Figure 2b). Most patients had sustained penetrating trauma (69,8%), 28,6% sustained blunt trauma and 1.5% of the causes were unknown (Figure 3). Only 28.6% had surgical emphysema, followed by 1.5% of chest wall hematoma and 8.5% of the cases had a combination of the two (Figure 4).

### Chest wall thickness – 2<sup>nd</sup> ICS MCL:

The mean  $\pm$  SD chest wall thicknesses of the left and right 2<sup>nd</sup> ICS MCL were  $41,03 \pm 15,24$  mm and  $41,77 \pm 15,83$ mm, respectively (Fig 5).

Figure 6 showed the average chest wall thickness in patients with penetrating versus blunt trauma. The left and right 2<sup>nd</sup> ICS MCL thicknesses in patients with penetrating trauma were  $39,85 \pm 13,4$  mm and  $40,47 \pm 13,19$  mm, respectively. For blunt trauma they were  $43,59 \pm 18,74$  mm and  $44,96 \pm 20,16$  mm, respectively. Figure 7 showed the average chest wall thickness in patients with and without surgical emphysema/ hematoma. The left and right 2<sup>nd</sup> ICS MCL thickness in patients with surgical emphysema/ hematoma were  $39,19 \pm 12,39$  mm and  $40,56 \pm 14,13$  mm respectively, whereas patients without surgical emphysema/ hematoma were  $42,88 \pm 17,55$  mm and  $43,00 \pm 17,40$  mm respectively. No statistical significance was observed in the 2<sup>nd</sup> ICS MCL thicknesses in patients sustaining penetrating versus blunt trauma ( $p=0.17$ ) (Fig 6) as for those with and without surgical emphysema or hematoma ( $p=0.20$ ) (Fig 7).

Figure 8 shows the average chest wall thickness for males and females. The left and right 2<sup>nd</sup> ICS MCL thicknesses in males were  $39,12 \pm 12,25$  mm and  $39,60 \pm 12,28$  mm respectively; whereas females measured  $51,29 \pm 23,85$  mm and  $53,42 \pm 25,48$  mm. The 2<sup>nd</sup> ICS MCL thickness difference of male compared to female patients was statistically significant ( $p=0.016$ ).

### **Chest wall thickness – other locations:**

The average chest wall thickness of the 3<sup>rd</sup> ICS MCL, 4<sup>th</sup> ICS MCL, 4<sup>th</sup> ICS AAL, 4<sup>th</sup> ICS MAL, 5<sup>th</sup> ICS MCL, 5<sup>th</sup> ICS AAL, 5<sup>th</sup> ICS MAL were 33.95, 27.18, 34.41, 41.31, 21.68, 28.42 and 36.31 mm respectively (Fig. 9). The chest wall thicknesses of the 2<sup>nd</sup> ICS MCL were significantly different to the other locations ( $p < 0.001$ ), except for the 4<sup>th</sup> ICS MAL ( $p > 0.05$ ).

### **Failure rate for needle decompression (Figure 10)**

Failed needle decompression was defined by the predicted inability of the 5 cm length angiocatheter to reach the pleural space as the chest wall thickness was greater than 50 mm. In this study, 32 patients (20.9%) would fail needle decompression at 2<sup>nd</sup> ICS MCL, irrespective of the side (either left or right). 20 patients (13.1%) would have failed needle decompression on both sides of the chest.

The top 3 locations with the highest failure rate for needle decompression were as follows, ranging from highest to lowest (Fig.7): right 4<sup>th</sup> ICS MAL (26.1%), 2<sup>nd</sup> ICS MCL right/ left (20.9%) and left 4<sup>th</sup> ICS MAL (19.6%). The top 3 locations with the lowest failure rate for needle decompression were as follows (Fig 7): right 5<sup>th</sup> ICS MCL (3.9%), left 5<sup>th</sup> ICS MCL (5.2%), left 4<sup>th</sup> ICS MCL (5.9%).

Only 24 of 33 (70%) of the female patients met the inclusion criteria, and among these patients, only 50% (12) with chest wall thicknesses exceeded 50 mm. The reason for exclusion in the remaining 30% of the patients were due to “images not within the field of view” owing to their breast sizes. This implied that more than half of the female patients would have required a longer angiocatheter.

### **Organ Injury (Fig. 10)**

The possibility of iatrogenic organ injury was assessed in all locations, except for the traditional 2<sup>nd</sup> ICS MCL, as this was thought to be the safest location for needle decompression. Organ injury was considered likely to occur if the adjacent organ abutted the pleura surface. The location with the highest rate of organ injury was the 4<sup>th</sup> ICS MCL (26%), followed by 5<sup>th</sup> ICS MCL (25%) and the 5<sup>th</sup> ICS AAL (6%). In our study, the safest location was at the 4<sup>th</sup> ICS MAL, where the predicted injury rate was 0%.

Figure 2a: Gender distribution

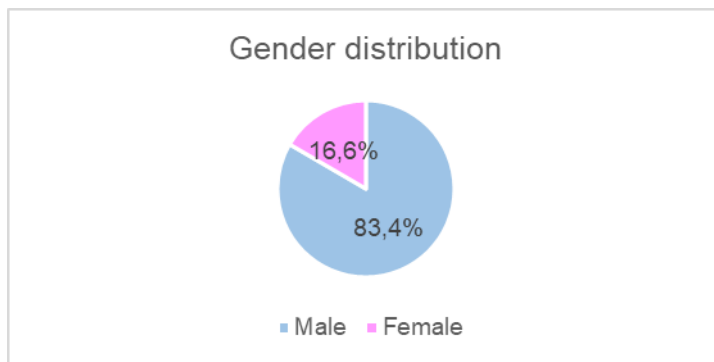


Figure 2b: Age distribution

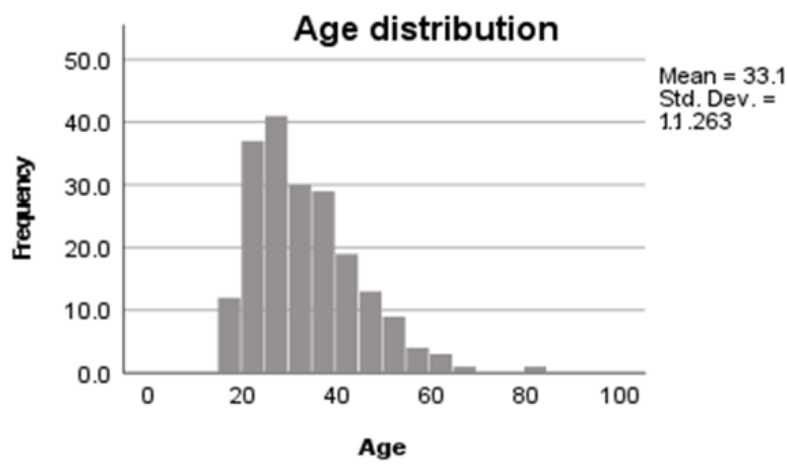


Figure 3: Type of trauma

		Trauma type		
		Frequency	Percent	Valid Percent
Valid	Penetrating trauma	139	69,8	70,9
	Blunt trauma	57	28,6	29,1
	Total	196	98,5	100,0
Missing	Unknown	3	1,5	
Total		199	100,0	

Figure 4: Presence of trauma related surgical emphysema/ chest wall hematoma

		Frequency	Percent	Valid Percent
Valid	None	84	42,2	42,2
	Surgical emphysema	57	28,6	28,6
	Hematoma	3	1,5	1,5
	Surgical emphysema and hematoma	17	8,5	8,5
	Images not within field of view	38	19,1	19,1
	Total	199	100,0	100,0

Figure 5: Average chest wall thickness for 2<sup>nd</sup> ICS MCL

		2nd ICS MCL right	2nd ICS MCL left
N	Valid	153	153
Mean		41,77	41,03
Median		39,00	38,00
Mode		36	30 <sup>a</sup>
Std. Deviation		15,831	15,238
Minimum		16	17
Maximum		116	127

Figure 6: Average chest wall thickness in 2<sup>nd</sup> ICS MCL in relation to type of trauma sustained

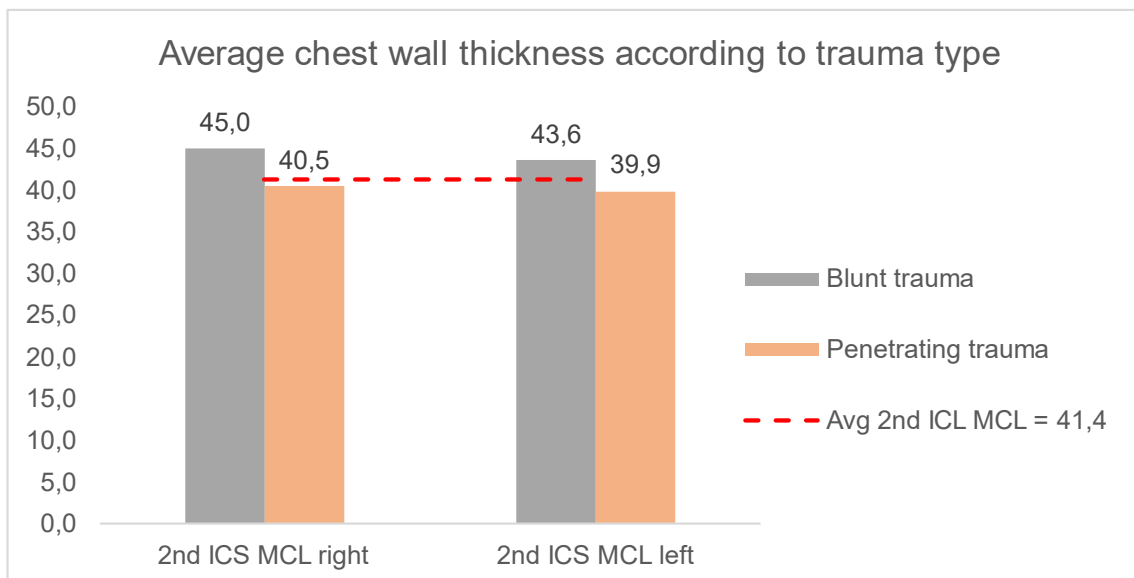


Figure 7: Average chest wall thickness in relation to post traumatic surgical emphysema/ hematoma

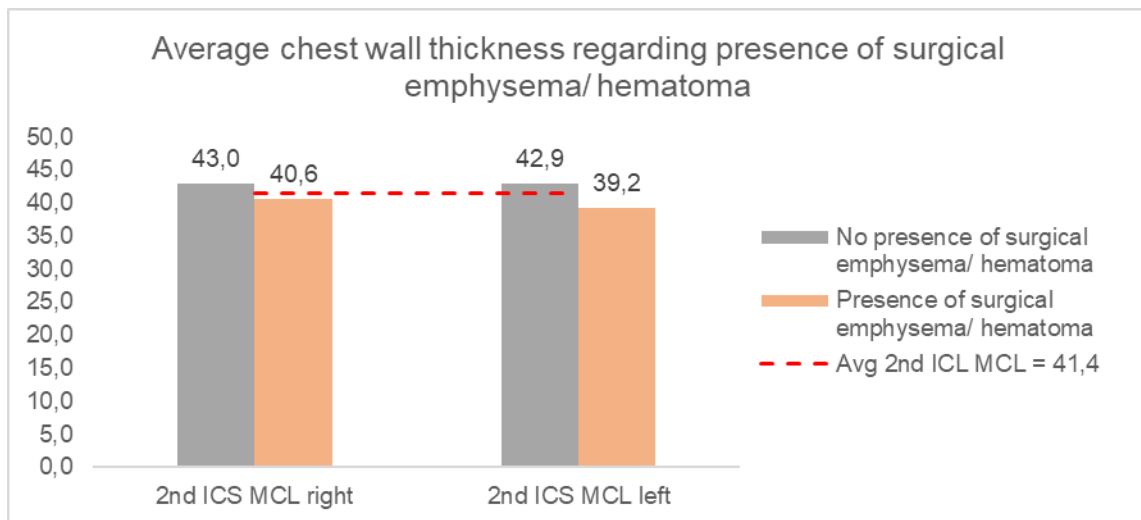


Figure 8: Average chest wall thickness in relation to gender

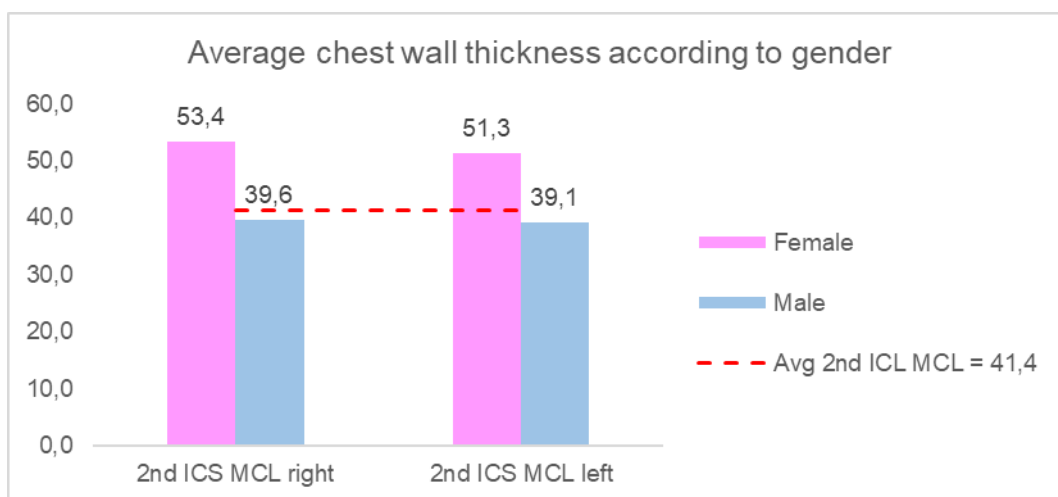


Figure 9: Average chest wall thickness in other locations

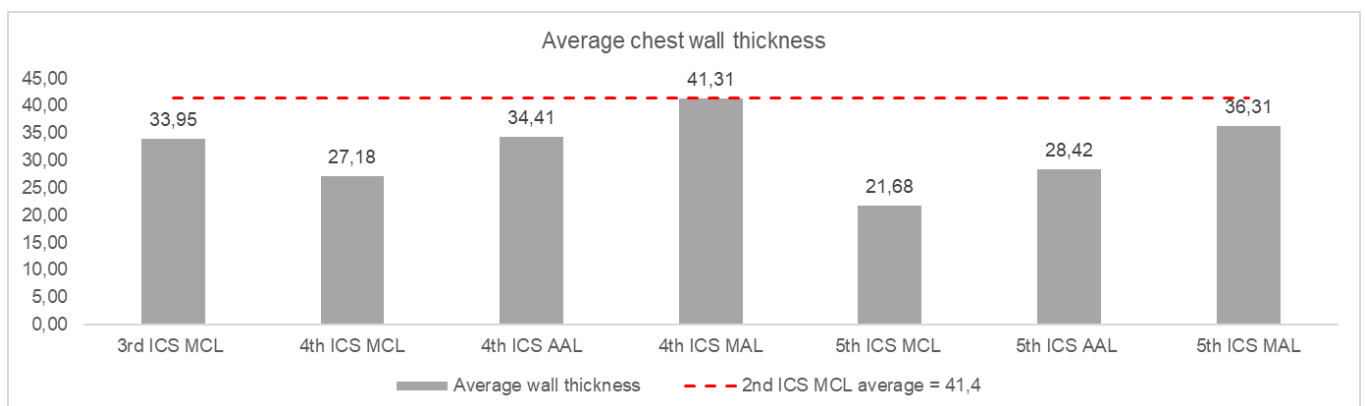
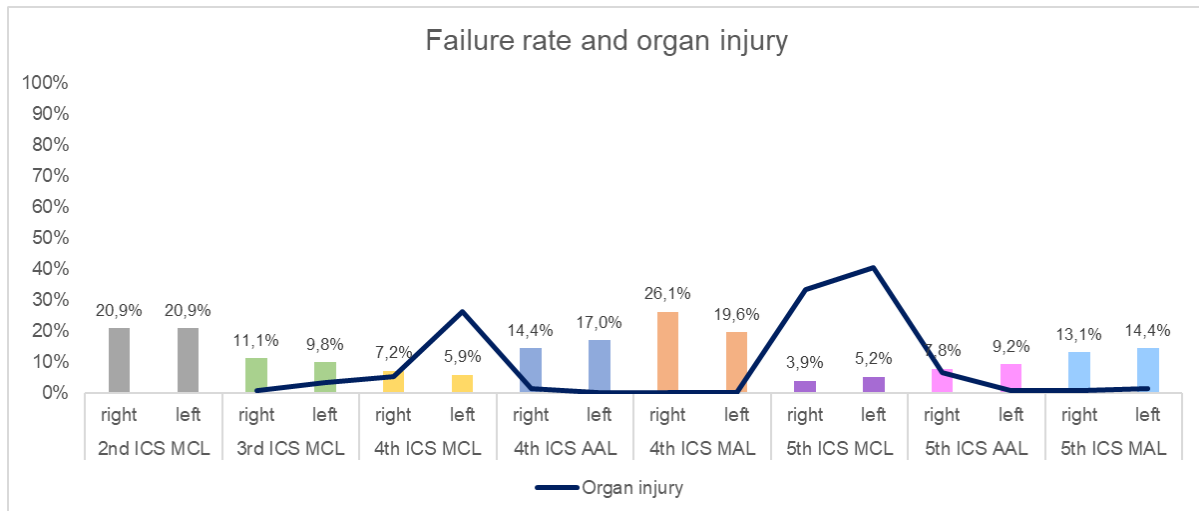


Figure 10: Failure rate and organ injury for specified locations. (No data was recorded for organ injury in 2<sup>nd</sup> ICS MCL.)



## Discussion

### Chest wall thickness:

The traditional site for urgent 50 mm needle decompression for tension pneumothorax was adequate in 79% at the 2<sup>nd</sup> ICS MCL. However, this may only be suitable for young male patients. Although the average chest wall thickness was less than 50mm at the 2<sup>nd</sup> ICS MCL, it was found that 32 out of 153 patients (20.9%) would have failed needle decompression at this level. This was similar to the findings from other studies .<sup>11,14</sup>

This study showed that gender consideration is required when choosing the length of the angiocatheter used, as the average chest wall thickness in females exceed the upper limit for the traditional 50 mm length angiocatheter. This may be due to the breast size, higher BMI or combination of both. This was also seen in studies performed in Japan and Texas <sup>18,19</sup>. Thus, an 80 mm angiocatheter would be beneficial in at least 50% of South African female patients.

In contrast to Azizi et al. and Chanthawattharak et al.<sup>15,16</sup>, this study showed that the average 2<sup>nd</sup> ICS MCL was thicker than the rest of the measured locations, including the lateral approach at the 4<sup>th</sup> and 5<sup>th</sup> ICS. The shortest average chest wall thickness was the 5<sup>th</sup> ICS MCL, followed by the 4<sup>th</sup> ICS MCL. These may be alternative sites for patients with high BMI or patients with thick breast tissue. Furthermore, needle decompression at the 5<sup>th</sup> ICS AAL site

with the 14G 50 mm long angiocatheter<sup>5</sup>, as recommended by the current ATLS (10<sup>th</sup> edition), would reach the pleural space in 140 patients (92%) in our study.

### **Organ injury:**

Iatrogenic organ injury is always a concern when inserting a needle blindly during needle thoracostomy. An 80 mm angiocatheter can have a 42% risk of iatrogenic cardiac injury at the 5<sup>th</sup> ICS AAL<sup>12</sup>, and 32% injury to the underlying organs (32%) at the 4<sup>th</sup> ICS AAL<sup>20</sup>. In our study, using the traditional 50 mm long angiocatheter, 10 of the patients (6%) would have sustained liver injury on the right side using the recommended 5<sup>th</sup> ICS AAL site. In addition, despite the 5<sup>th</sup> ICS MCL and 4<sup>th</sup> ICS MCL spaces have the shortest chest wall thickness, these had the highest risk of iatrogenic organ injury. Thus, these potential alternative sites for needle thoracostomy with the 50 mm angiocatheters in patients with high BMI or large breast tissues would be unsafe. The safest location with no iatrogenic organ injury in this study was the 4<sup>th</sup> ICS MAL. Although the average chest wall thickness at this location was still within normal limits (41 mm), there was a high risk of failure (29 %) when using the 5 cm angiocatheter. Thus an 8 cm angiocatheter should be considered balanced against the risks of iatrogenic injury using a longer needle.

### **Limitations:**

There were several limitations to this study. First, the patients entering the GSH Trauma centres were primarily young males. Future studies to include and assess patients from the medical emergency centre, and other provincial medical centres, may provide a more accurate average chest wall thickness in the South African population. Second, as no data were available for height and weight, the findings could not be correlated to the patients' BMI. This may be an important finding, as several studies found that BMI predicts the length of catheter needed for needle decompression.<sup>17,21</sup> Depending on the location of injury, the positioning of the arm during CT scan as per protocol could play an important role in determining the chest wall thickness. The ipsilateral chest wall with the arm elevated would be thinner in comparison to the contralateral side with the arm alongside the chest. The arms were likely to be down during needle thoracostomy in an emergency, therefore this study may be underestimating the chest wall thickness in a clinical setting. Fourth, similar to Azizi et al (2021), this study was only able to assess a hypothetical failure rate for needle

decompression. In the clinical setting, many other important factors must be taken into consideration as a cause of failure to decompress the tension pneumothorax. These include blood or tissue obstructing the catheter lumen, kinking of the catheter, small catheter diameter, angle of the needle inserted in relation to the pleura, as well as the medical personnel performing the needle compression. In addition, tissue compressibility of subcutaneous fat versus that of chest wall muscles should also be considered. Finally, many of the patients excluded from the study due to images not within the field of view may have been due to increased chest wall thickness from extremely high BMI or large breast tissues. Excluding these patients could falsely decrease the failure rate of needle decompression at 2<sup>nd</sup> ICS MCL.

## **Conclusion**

This study showed that more than 20% of patients, and particularly more than 50% of female patients would fail needle decompression using the traditional 14 G 50 mm angiocatheter at the 2<sup>nd</sup> ICS MCL during the immediate management of tension pneumothorax. In South Africa, the thinnest chest wall thickness was at the 5<sup>th</sup> ICS MCL, however the risk of iatrogenic organ injury increased drastically at this level. On the contrary, while the 4<sup>th</sup> ICS MAL is the safest point in protecting against iatrogenic organ injury, more than a quarter of patients would fail needle decompression. Therefore, the preferable site for needle decompression with the traditional 14G 50 mm long angiocatheter in South African patients would be the 5<sup>th</sup> ICS AAL, due to the low failure rate and reduced risk of iatrogenic organ injury.

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## **Competing interests**

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

## **Authors' contribution**

J Chang was the lead author, Q Said-Hartley was the supervisor.

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