University of Cape Town
Department of Surgery
Division of Emergency Medicine

The HI-MAP scan:
The use of emergency ultrasound to evaluate haemodynamically unstable patients

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A dissertation to be submitted in partial fulfilment of the requirements for the degree of MPhil Emergency Medicine

Student:	Ignatius Postma
Degrees:	MBChB (Pret) , DipPec (SA)
Affiliation:	University of Cape Town and Stellenbosch
Student Number:	PSTIGN001
Primary Supervisor	Prof Lee Wallis (UCT: 01401390)
Co- Supervisor	Darryl Wood

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Abstract

The HI-MAP scan is a focussed ultrasound examination designed to assess the hydration status of patients by looking at the heart, inferior vena cava, abdomen, aorta and chest. In the Emergency Centre (EC) this non-invasive tool can assist in early accurate diagnosis of critically ill patients.

Aim

The aim of this study is to demonstrate the use of the HI-MAP scan in a regional EC in KZN to assist in assessment of hydration status of critically ill patients.

Methods

This is a cross sectional retrospective descriptive study of HI-MAP scans performed on haemodynamically unstable patients who were admitted to the EC at Ngwelezane Hospital from January 2010 until October 2011. Diagnosis before and after ultrasound, times and specific ultrasound findings were documented and analysed.

Results

A total of 133 patients were included. When provisional compared to final diagnosis after ultrasound, 87 patients had the same and 46 had different diagnosis confirmed by HI-MAP. A third of the patients had a different diagnosis after the HI-MAP scan was performed. In fluid overloaded patients 95% had either poor contractility or Inferior vena cava collapsibility index (IVC-CI) of less than 25%. In hypovolaemic patients 96% had either hyperdynamic cardiac contractility or IVC-CI of less than 50%.

Conclusion

HI-MAP scan is a good non-invasive tool for volume assessment. Cardiac contractility and IVC-CI are the two most sensitive components of this scan to predict hydration status in critical patients.

E-mail

Naas10@gmail.com

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Glossary of abbreviations

Abbreviation	Meaning
AAA	Abdominal aortic aneurism
ACES	Abdominal and cardiac evaluation with sonography in shock
APWA	Arterial pulse wave assessment
CCF	Congestive cardiac failure
CI	Collapsibility index
CT	Computer tomography
CVA	Cerebro vascular accident
CVP	Central venous pressure
DVT	Deep venous thrombosis
EC	Emergency centre
ECG	Electro cardiogram
EF	Ejection fraction
EFAST	Extended focussed sonography in trauma
EMSSA	Emergency Medicine Society of South Africa
EP	Emergency physician
ECRU	Emergency centre resuscitation unit
EUS	Emergency ultrasound
FAST	Focussed assessment sonography in trauma
FEEL	Focused echocardiographic evaluation in life support
FEER	Focused Emergency Echocardiography in Resuscitation
FOCUS	Focussed cardiac ultrasound
GCS	Glasgow coma scale
ICU	Intensive care unit
IVC	Inferior vena cava
IVC-CI	Inferior vena cava collapsibility index

IVS	Inter ventricular septum
JVP	Jugular venous pressure
LV	Left ventricle
LVEDV	Left ventricular end diastolic volume
MV	Mitral valve
NPV	Negative predictive value
PAC	Pulmonary artery catheter
POCUS	Point of care ultrasound
PPV	Positive predictive value
RU	Resuscitation unit
RUSH	Rapid ultrasound in shock and hypotension
RV	Right ventricle
SVR	Systemic vascular resistance
TV	Tricuspid valve
UHP	Undifferentiated hypotension patient ultrasound protocol

1 Introduction

The emergency centre (EC) is the most likely post of first call for patients who are haemodynamically unstable. Clinically the haemodynamic status of a patient is determined by assessing basic cardiovascular parameters such as blood pressure, pulse rate, respiratory rate and urine output. These vital sign parameters can be non-specific when trying to determine the cause of shock and when trying to monitor the response to treatment. It is unreliable without more specific and quantitive ways of determining fluid status.[1] Rady et al. suggested in 1996 that when using central venous oxygen saturation, serum lactate and shock index in combination with vital signs is the most accurate way to determine whether the patient is in a shocked state and more accurate in monitoring the patient's response to treatment. Central venous pressure (CVP), pulmonary artery catheter (PAC) and arterial line blood pressure monitoring with arterial pulse wave assessment (APWA) are additional invasive methods to determine and to monitor haemodynamic status in patients. Therefore, determining the level of shock, the cause and monitoring a patient's response to treatment, requires a number of tools, some of which are not always available and may also be time consuming.

Rapid and accurate diagnostics in shocked patients is challenging in the emergency setting where time is of the essence. We can determine the cause of these physiological abnormalities by taking a history, clinical examination, bedside tests and special laboratory investigations. More specialized investigations such as computer tomography (CT) scan and radiologist performed abdominal ultrasound or echocardiogram is often needed to establish an accurate diagnosis. These special investigations are time consuming and not always readily available especially after hours. Diagnosis in the emergency centre is thus mostly reliant on the emergency physician's (EP) ability to make an early diagnosis and initiate treatment. Further diagnostics usually continues after the patient has been stabilized.

Emergency physicians can make accurate diagnosis without access to all the special investigations. A study performed in 2010 showed that presumptive diagnosis made by the EP was accurate in 93% of cases.[2] In another study the presumptive or initial diagnosis made by the EP was only 81% accurate.[3] In this study the use of special investigations was demonstrated to be as low as 36% in all cases. In the cases where special investigations were used to aid in the diagnosis, the accuracy of the diagnosis was the same. The conclusion made in both these studies was that special investigations in the EC did not make a significant difference in the initial diagnosis. These investigations could also not be performed due to time limitations. Unstable patients had to be treated first and further special investigations be performed when they were stable.

Shock is defined as a state of poor perfusion that leads to poor oxygenation of vital organs, the start of anaerobic metabolism with the production of lactate, metabolic acidosis and eventually cell death, multiple organ failure and death. Hinshaw and Cox classified and described the four basic states of shock in 1972[4] as:

1) Hypovolaemic shock
2) Distributive shock: septic shock, anaphylaxis, neurogenic shock
3) Obstructive shock: Cardiac tamponade, tension pneumothorax, pulmonary embolus, aortic stenosis
4) Cardiogenic shock

This classification is still used today. Shock can thus be attributed to reduced pre-load (volume), poor cardiac function and afterload (systemic vascular resistance) or a combination thereof. Reduction in any of these can lead to poor tissue perfusion, anaerobic metabolism and build-up of lactate with metabolic acidosis. Pre-load can also be excessive, causing cardiac dysfunction with poor contractility due to dilation of the myocardium and eventually lead to cardiac failure. Similarly a primary myocardial problem such as an acute myocardial infarction (MI) can reduce cardiac function due to poor contractility and cause poor cardiac output, even with a normal pre-load. This also leads to poor tissue perfusion with similar end results. Due to the complex nature of the physiology it is sometimes difficult to determine the exact cause of the shocked state with clinical methods only. In the EC the emergency practitioner often faces the dilemma of defining the cause of shock with limited time and tests available. Treatment needs to be started urgently since these patients are unstable and could deteriorate and have an imminent cardiac arrest. Even though the EP has been shown to be reasonably accurate when making a diagnosis, it has been shown that EP's are not accurate when trying to determine cardiac output and volume status. [5] This was highlighted in a study by Nowak et.al. which compared EP clinical assessment to objective quantitive measurement of cardiac output such as the non-invasive finger cuff technology that gives continuous blood pressure and cardiac output monitoring.The EP will evidently need special equipment and skills to assist in evaluating and monitoring hydration status in critically ill patients in order to make the diagnosis more accurate and treatment more appropriate

Traditionally invasive methods of volume assessment such as central venous pressure (CVP) measurement have been used as the standard of care. With proper measuring technique and consideration of cardiac output, CVP monitoring is helpful in determining haemodynamic status.[6] Even though still used in many centres, CVP measurement is not recommended as a good stand-alone tool to determine haemodynamic state. A systematic review demonstrated a poor relationship between CVP measurement and blood volume. It also showed as well as the inability of CVP or change of CVP measurements to predict response to a fluid challenge[7]. Unfortunately, no easily accessible alternative is suggested. In emergency medicine in rural South Africa, CVP measurement is still part of daily practice. It is thus important that the use of CVP must be done with a great understanding of the physiology of the patient and can therefore not be used as a single measure of fluid status. All clinical findings and suspected pathology must be considered and be interpreted with the CVP measured values. CVP response to fluid boluses could also be assessed.

The use of PAC has been challenged and has been used less frequently in the critical care setting due to conflicting findings in the outcome of patients. [8] In 2005 a randomized controlled trial compared the outcome of over 1000 patients with PAC monitoring vs. no PAC monitoring.[9] There was no benefit when mortality rates and hospital stay were compared between the two groups. The study did not incorporate the accuracy of PAC measurement. The PAC group did have more complications due to the invasive nature of the procedure. They also noticed that there were significant problems with the interpretation of PAC measured results and inaccuracy. It has also been suggested in the past that PAC could have an increased mortality risk.[10]

Arterial pulse wave assessment (APWA) with intra-arterial blood pressure monitoring has been used to determine cardiac output, using different techniques[11]. It can also be referred to as pulse pressure analysis or pulse contour analysis.[12]These methods have their own unique complications due to their invasive nature. Less invasive methods have been suggested for haemodynamic monitoring .The use of simple focussed bedside ultrasound and combining it with clinical findings may lead the clinician to making a more accurate diagnosis.[13] The current standard of care of volume status measurement in the critical care setting is trans-oesophageal and transthoracic cardiac echo performed by the radiologist. [14] Exact quantitive volume assessment with trans-thoracic echo is complex and needs specialist skills and experience to be performed accurately. Emergency ultrasound (EUS) has subsequently been developed as a more simple and rapid aid to the EP. It has been aptly known as point of care ultrasound (POCUS)

The aim of EUS is to be used as an early diagnostic adjunct in order to assist the emergency practitioner in the assessment haemodynamically unstable patients and to guide immediate therapy. In a multi-centre ICU study in 2009, clinical examination with using hand held ultrasound and clinical examination without ultrasound on 354 patients was compared to see if there was a difference in the accuracy of the final diagnosis, when assessed by a cardiology expert.[15] The group with ultrasound examination included improved the accuracy from 67% to 88%. The addition of the US assessment significantly improved the accuracy of diagnosis. In order to be effective and used on a regular basis, EUS must have specific characteristics.

The characteristics of EUS are[16]:

- A clear indication for a defined condition.
- Goal directed, i.e. focussed and limited.
- Findings must be easily recognizable.
- The type of scan needs to be easy to learn.

- The scan should be quick to perform.
- The scan result should effect the clinical decision making process.
- It should be performed at the bedside in real time.

Various ultrasound examinations have been described in the literature to determine the cause of undifferentiated shock. (Table 1) A new acronym appears almost every year. All these scans include a basic assessment of haemodynamic status by evaluating combinations of preload, cardiac contractility, ventricular filling, inferior vena cava collapsibility and potential sights of haemorrhage such as the abdomen, pleural cavity and aorta. Many views used in the scans overlap each other in one or more ways. Some scans even include assessment for deep vein thrombosis and ectopic pregnancy.[26] However; little research has been done to test the efficacy of any of these scans to really determine the cause of shock or the response to treatment. To decide which one of these scans to include into a departmental guideline becomes difficult. The reasoning used in all these reviews seemed to be the same: in order to assess shock in a patient one has to look at the following physiological functions and interpret the findings appropriately to determine the type and cause of shock:

- Preload: IVC and RV collapsibility or distension
- Cardiac function or contractility: Hyper dynamic, normal or poor
- Other areas of potential volume loss: Peritoneal cavity, pleural space
- Other areas of potential mechanical causes of shock such as pneumothorax, DVT with PE or pericardial effusion with tamponade

Name of scan	Description	Purpose of scan	Views
FAST[17]	Focussed assessment sonography in trauma	Scan for free fluid abdomen and pericardium	• Right hepatorenal view • Left hepatosplenic view • Subxiphisternal view • Suprapubic view
EFAST[18]	Extended focussed assessment sonography in trauma	Free fluid and detection of pneumothorax	• Right hepatorenal view • Left hepatosplenic view • Subxiphisternal view • Suprapubic view • Pleural views
ACES[19]	Abdominal and cardiac evaluation with sonography in shock	Determination of cause of shock	• EFAST • Cardiac • IVC • AAA • DVT
FEER[20]	Focused Emergency Echocardiography in Resuscitation	Cardiac Movement	• Cardiac
FOCUS[21]	Focussed cardiac ultrasound	Cardiac function and hydration status	• Cardiac • Global systolic function • Right ventricle enlargement • Pericardial effusion • IVC
RADiUS[22]	Rapid assessment of dyspnoea with ultrasound	Determination of cause of dyspnoea	• Cardiac • IVC • Pleural effusions • Pleural line
RUSH[23]	Rapid ultrasound in shock and hypotension	Determination of type of shock and cause of shock	• Heart • FAST • IVC • AAA • Pneumothorax
UHP[24]	Undifferentiated hypotension patient ultrasound protocol	Determination of cause of shock	• FAST • Cardiac • AAA
FEEL[25]	Focused echocardiographic evaluation in life support	Determination of cause of shock and cardiac movement	• Cardiac
FAST and RELIABLE[26]	Undifferentiated hypotension using mnemonic FAST and RELIABLE	Determination of cause of shock	• FAST • Cardiac • AAA • IVC • DVT • Pneumothorax • Ectopic pregnancy

Table 1: Acronyms for scans used in practice IVC inferior vena cava, AAA abdominal aortic aneurism, DVT deep venous thrombosis

In our study we adapted the mnemonic “HI-MAP” from Perera et.al.[23], which describes the views for the RUSH (rapid ultrasound in shock and hypotension) scan. The RUSH scan is designed to assess hydration status of a patient. It includes basic views that overlaps with many of the scans mentioned above:

- **H -** **H**eart or cardiac views
- **I -** **I**nferior vena cava filling
- **M -** **M**orison’s pouch or abdominal FAST views
- **A -** **A**orta
- **P -** **P**neumothorax

The reason for using the HI-MAP-scan is twofold: the acronym is easy to remember and all the views and assessments are level 1 basic emergency ultrasound skills. The HI-MAP scan can be performed at the bedside, using a curvilinear transducer at a frequency of 5 MHz (abdominal probe). Despite only being described to determine the type and origin of undifferentiated shock, it can also be used to determine whether a patient is fluid overloaded or in cardiac failure. Thus, the purpose of the HI-MAP scan is to determine whether the patient is overloaded, dehydrated, has cardiac pathology and to aid in finding a cause of the abnormality. As discussed above, EUS must be focussed and limited. It is used to assess the haemodynamic status of a patient by answering focussed binary questions, e.g. “yes” or “no”; “positive” or “negative”; ”present” or “not present”.

The evidence for the effect of these types of scans on outcomes is scanty. However, there are various studies published that look at the outcomes and efficacy of individual parts of these scans, such as cardiac function, IVC collapsibility, FAST , detection of AAA and accuracy of identifying ectopic pregnancy. The rest of this chapter focuses on the evidence of these individual parts of the HI-MAP scan under the appropriate headings.

1.1 HI-MAP – "The evidence"

1.1.1 Heart or cardiac scan

The "H" in HI-MAP stands for heart or cardiac scan. This is a focussed EUS assessment of the heart to assess preload, contractility and the pericardium for the presence of an effusion with or without cardiac tamponade. The cardiac scan can be performed through three different views[27] (Fig 1):

- Parasternal long axis
- Apical four chamber view
- Sub-xiphoid long axis

Depending on the type of transducer available and the body habitus of the patient, all three the views or just one view could be used to make a proper assessment of global cardiac function. Like in all emergency ultrasound examinations this scan is focussed. The aim is to answer the following binary questions:

1. Is the cardiac contractility good or poor?
2. Is there a pericardial effusion?
3. If there is an effusion, is it causing cardiac tamponade?
4. Is the right ventricle filling good or poor (collapsing)?

1.1.1.2 Cardiac contractility

When looking at cardiac contractility, it is well established that a visual estimation by the sonographer is adequate to determine global cardiac function by describing good, normal or poor contractility[39] The American College of Emergency Physicians and the American Society of Echocardiography determined in a consensus statement that the cardiac scan could be used to assess patients for pericardial effusion, global cardiac contractility and left or right ventricular enlargement.[21] It could also be used to determine preload by looking at the IVC in combination with cardiac contractility and right ventricular filling. Further evidence shows that EP ultrasound scans have similar accuracy to radiologist performed scans when identifying the cause of hypotension, but have the benefit of being performed sooner at the bedside of the patient.[28] This indicates that there is no need to perform complicated calculations like ejection fraction and ventricular apical shortening to get an accurate assessment of cardiac contractility. Melamed et al. performed a small double blind observational study in 2009 comparing trans thoracic echo (TTE) performed by cardiologists with minimally trained ICU specialists in 44 patients in the ICU.[29] The results showed that 92% of patients with normal left ventricular (LV) function and 80% of patients with abnormal LV function were correctly diagnosed by the ICU specialist when compared to the experienced echo cardiographers. Even though the correlation was not 100%, the accuracy was still acceptable and considering that the scan could be performed immediately at the bedside, it would significantly contribute to early diagnosis and initiation of emergency treatment. Cardiac contractility and ejection fraction has been shown to be of similar accuracy when performed by paediatric EP's[30].

The evidence demonstrates that EP performed echo of critically ill patients is as accurate as radiologist or cardiologist performed echo. (Table 2) Most of these studies were small and no study tested the outcome measures in terms of mortality, morbidity or length of hospital stay. Numerous reviews have been published (Table 1) and several case studies were included in these reviews. There is no single instrument or observation that is 100% effective in determining volume status. The gold standard of volume assessment in all these studies was thus a combination of clinical examination, cardiac echo and invasive cardiac output monitoring as interpreted by the clinician.

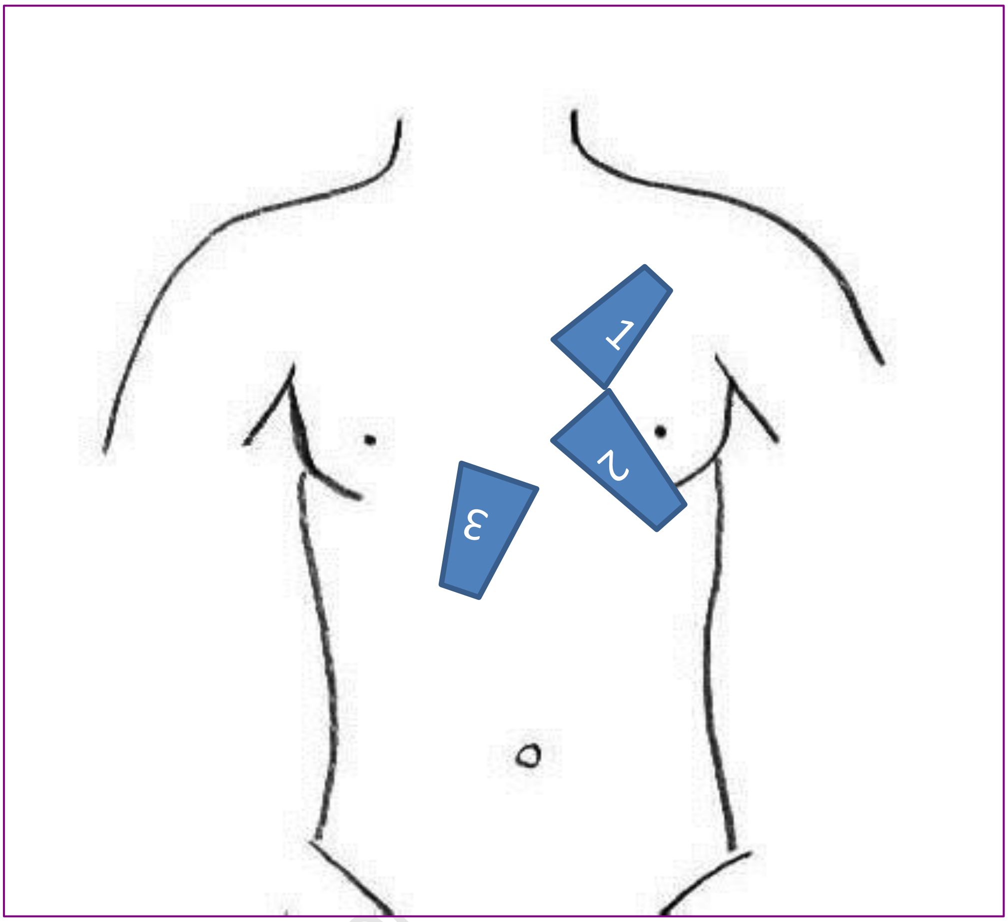


Figure 1: 1- parasternal long axis view, 2- apical four chamber view, 3 - sub-xiphoid view

Reference	Methods	Results	Comments
Khouli et.al[31] 2011	Prospective blinded cohort study with 51 patients in ICU, comparing pulmonary artery catheter, trans thoracic echo and clinical examination to determine cause of cardiopulmonary compromise. Clinical examination and assessment by specialist was taken as gold standard for determination of cardiopulmonary compromise	Complete correlation between TTE and right heart catheterization to determine cause of cardiopulmonary compromise in 90% of patients. PPV and NPV of 93% and 97% respectively to predict cause cardiopulmonary compromise with TTE	Used estimation of ejection fraction, LVEDV and IVC diameter. IVC diameter more than 2cm=RAP more than 15 mm Hg
Wang et.al.[32] 2010	Prospective observational study comparing diagnosis of acute heart failure using B-natriuretic peptide (BNP) with cardiac echo in 84 patients in emergency unit	Reduction in left ventricle ejection fraction and LVEDD in patients with raised BNP. Very helpful in patients with intermediate BNP to finalize diagnosis	No sensitivity or specificity determined
Martin et. al.[33] 2009	10 non cardiologist hospital doctors compared clinical examination alone with combination of clinical examination and TTE, using cardiologist performed echo as gold standard n= 354	Clinical examination alone showed 46% correlation to Gold Standard and 59% correlation when bedside echo was included.	The use of bedside EUS improves clinical assessment of cardiac function and hydration status of critically ill patients.
Mark et.al.[34] 2007	Prospective investigator blinded study to determine the best window for bedside cardiac echo and EF determination by ICU doctors. n=70	Parasternal long axis view was rated as the best view on a five point Likerd scale.	Good inter investigator correlation in estimation of EF with parasternal long axis view.
Liu et.al.[35] 2005	Cohort study comparing clinical examination in combination with portable or standard echo machines to make an accurate diagnosis in cardiomegaly n=100	Portable unit used at bedside improved clinical accuracy from 62% to 83% when compared to clinical examination only; the same as standard echo	Bedside echo recommended for cardiac assessment by EP's.
Randazzo et. al.[36] 2003	Accuracy of estimation of left ventricular function and CVP when EUS compared to radiologist performed cardiac echo in ICU n=115	86% overall agreement between radiologist and EP echo. 92 % agreement with normal EF and 72% with poor EF	Good correlation between formal echo and EP performed echo.
Moore et. al.[37] 2002	Prospective observational study to compare EP estimation of EF to cardiologist performed echo n=51	Pearson's correlation coefficient of R=0.86.	EP's can accurately determine EF with bedside EUS or echo evaluation.
Mueller et. al.[38] 1991	Blinded prospective observational study in ICU on 40 consecutive patients comparing biplane contrast ventriculography (gold standard) to visual estimate of ejection fraction	Correlation of 81% was found between gold standard and visual estimate by ICU doctors	Visual estimate of EF better than any direct measurements by ICU doctors

Table 2: Literature review of emergency cardiac sonography. PPV positive predictive value, NPV negative predictive value, TTE trans-thoracic echo, LVEDV left ventricular end diastolic volume, RAP right atrial pressure

1.1.1.3 Pericardial effusion

Pericardial effusions can be diagnosed clinically using Beck's triad; muffled heart sounds, low blood pressure and distended neck veins, only if cardiac tamponade is present. Sub clinical pericardial effusions can easily be missed on clinical examination.[39] Chest x-ray can be helpful in demonstrating a globular heart; ECG can show small QRS complexes, t-wave inversion and ST depression. All these signs are non-specific and could lead to missing the diagnosis of pericardial effusion. Pericardial effusions can be seen as a dark line around the heart surrounded by the hyper echoic or white pericardium (appears white). A study done in 1974 on 41 patients where echo findings were compared to surgical aspiration of pericardial fluid, showed that pericardial separation can be seen on echo with as little as 15-30ml of fluid.[40] They graded the size of effusions as:

- Small (echo-free space in diastole <1cm)
- Moderate (1–2c m)
- Large (>2 cm)
- Very large (>2 cm +/- compression of the heart)

Pericardial effusions are easy to diagnose with two-dimensional ultrasound from a sub-xiphoid view, parasternal long axis view or apical four chamber view. The sub-xiphoid view is usually adequate. (Fig. 2) A study done on 515 patients to test the accuracy of cardiac ultrasound in pericardial effusions performed by EP's demonstrated sensitivity of 96% and specificity of 98% to diagnose clinically significant pericardial effusions.[41]

It makes sense then that this test should be included into the HI-MAP scan. With such high sensitivity and specificity, the identification of a pericardial effusion can lead to early diagnosis and treatment of the patient with undifferentiated shock or haemodynamic instability. Pericardial effusions can be sub clinical (chronic and asymptomatic) and its presence might not be the reason for decompensation.

Once the diagnosis of a pericardial effusion was made, the next step in the HI-MAP protocol would be to determine whether it is causing a cardiac tamponade. (Perera et al)[23]

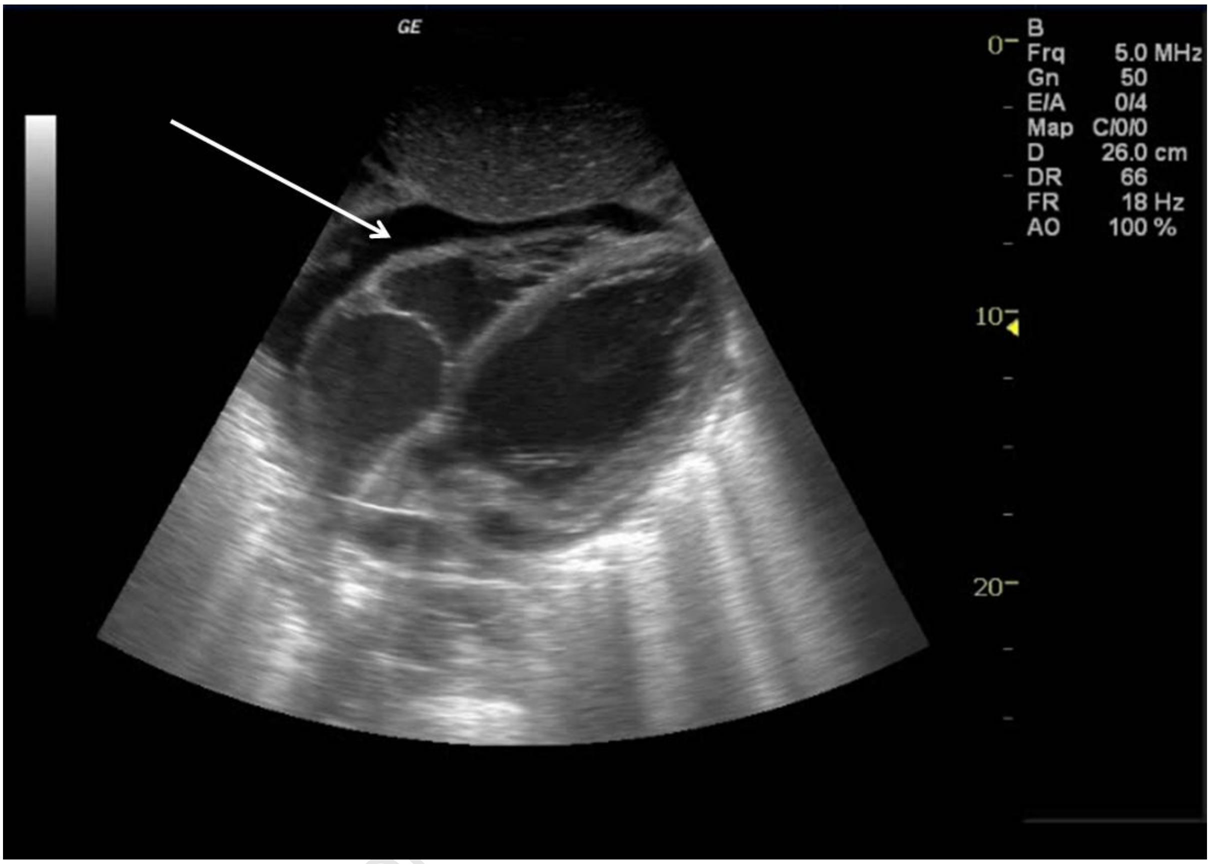


Figure 2: Pericardial effusion as seen with sub xiphoid ~~xiphisternal~~ view; the arrow indicates a pericardial effusion

1.1.1.4 Cardiac tamponade

It is more complicated using EUS to identify cardiac tamponade, especially during the early stages.[42] Clinically symptoms might be as subtle as mild dyspnoea on excursion or as severe as systemic collapse and cardiac arrest. Clinically it could be diagnosed by Beck's triad as mentioned above. These clinical signs are only present in 10-40% of patients with cardiac tamponade.[43] The presence of increased CVP or distended neck veins is the most sensitive sign in the presence of Beck's triad.[44]

Other clinical investigations include ECG, chest x-ray and CT scan. In the presence of significant cardiac tamponade, these investigations will not be practical since the patient is usually too unstable and distressed to perform them. Ultrasound at the bedside is an ideal tool that is a readily available investigation that can be performed by the EP.

Cardiac tamponade is recognized on EUS by revealing diastolic collapse of the right ventricle, and a dilated non-collapsing IVC. Nagdev[53] also indicated that right ventricular collapse and IVC plethora (dilated and non- collapsing) are the only useful tools in the diagnosis of cardiac tamponade for the average emergency sonographer with limited training. Identifying right ventricular diastolic collapse can be difficult especially if the patient is tachycardic and simultaneous ECG monitoring is not available. Furthermore there are other conditions that can cause right ventricular collapse such as right sided pleural effusion and severe hypovolaemia. There are also conditions that could prevent RV collapse such as pulmonary hypertension and cor pulmonale. Clinical assessment of the patient and an accurate history is once again crucial in this diagnosis. If the patient is perfectly stable with normal vital signs and no distress, it is unlikely that he/she would be in cardiac tamponade even if there is a pericardial effusion present. If the patient is in severe shock and distress and a pericardial effusion is present, cardiac tamponade should be suspected.

1.1.1.5 The right ventricle, cor pulmunale and pulmonary embolism (PE)

The right ventricle (RV) is smaller and less muscular than the left ventricle (LV) and also has to endure less pressure than the LV. Clinically RV strain can be identified by enlarged tender liver, peripheral pitting oedema and distended neck veins or a raised jugular venous pressure (JVP). The diagnosis of PE is notoriously difficult. Special investigations for the assessment of RV function and the presence of PE include the 12 lead ECG that might show "S1,Q3,T3," chest x-ray with wedge shaped opacification or an arterial blood gas with an increased alveolar arterial oxygen pressure gradient (A-a gradient) . A study in 1996 showed that the best results for identifying PE is a combination of ECG, clinical findings and cardiac echo with M-mode RV:LV ratio and tricuspid regurgitation flow rate.[45] On ultrasound examination the RV is assessed in relation to the LV. The RV is supposed to be no bigger than 60% of the LV diameter. No studies have been done to demonstrate the accuracy of estimation of RV to LV ratio without direct measurement of the diastolic M-mode diameter of the ventricles. In our study we decided to use this estimation method and only made a remark about the RV if it was clearly the same size or bigger than the LV. If a proper four chamber view or sub-xiphoid view can be obtained, comparison of ventricle size is obvious.

According to Vieillard-Baron et.al the most accurate way to assess the RV function is to compare the end diastolic RV and LV areas on apical four chamber view. [46] They also indicate that reduction in wall movement and presence of dilatation can point towards acute RV strain and even massive PE. Other conditions such as valvular disease and acute myocardial infarction can present with similar ultrasound findings. It is thus important to do the bedside echo after clinical examination and particularly to look for RV failure, cor pulmonale and PE if clinically suspected.

A case report in 2011 suggested that there are two ways to identify pulmonary embolism with ultrasound: direct or indirect. [47]The direct method has a high specificity i.e. rule in and low sensitivity. The direct method with trans-thoracic echo incorporates observing an actual clot in the right ventricle or pulmonary arteries. The indirect method has poor specificity with moderate sensitivity and involves the following:

- RV dilatation
- RV dysfunction
- Interventricular septum flattening
- Inferior vena cava distension or plethora with no inspiratory collapse
- Deep venous thrombosis

The indirect method also includes McConnell sign which is described as hypokinetic free wall motion with normal apical movement.

1.1.2 Inferior vena cava assessment

Inferior vena cava (IVC) diameter can be measured using bedside ultrasound. The IVC diameter in any normal adult varies with inspiration and expiration. During inspiration the intrathoracic pressure decreases and the IVC diameter decreases to reach a minimum diameter at the end of inspiration. At the end of expiration the IVC diameter reaches a maximum as does the intrathoracic pressure. Many studies have been performed to determine the correlation between fluid status, CVP measurement and the IVC diameter in various different positions. Table 3 is a literature review that shows all major publications on ultrasound assessment of the IVC and the outcomes. As mentioned already there is a poor correlation between CVP measurement with right atrial catheterization and actual hydration status of a patient. It is however still used in conjunction with clinical assessment of patients to evaluate and monitor hydration status in the critically ill.

In order to make the measurement of IVC in EUS as accurate and significant as possible we searched the literature to determine the following:

- Best correlation between hydration status and IVC diameter
- Best correlation between collapsibility of the IVC during inspiration: collapsibility index (CI)
- Best site/view with EUS to measure the IVC
- The use of diameter only or CI or a combination of both

When comparing the relationship between CVP and IVC diameter per se, the correlation seems to be less accurate. Lyon et.al did a study in 2004 on 31 volunteers and measured the IVC at end of expiration as well as inspiration and then compared the diameters right after donating 450 ml of blood. [48] A total of 31 volunteers were included and the results showed a significant reduction 5mm in the IVC diameter after blood loss. This was a small study and did not incorporate physiological compensation after a few hours. The study subjects were all healthy patients without any underlying pathology that could significantly alter the physiology and ultrasound observations.

Another study done in 2007 showed that there was a good correlation between the IVC diameter and hydration status.[49] They compared the IVC-Aorta (IVC-A) ratio of 36 children with confirmed dehydration due to gastro enteritis to the IVC-A ratio in 36 euvolaemic children of similar age and weight. The IVC-A ratio was significantly smaller in dehydrated children which suggested that there is a correlation between IVC diameter and hydration status. The study population was small and the age range of 6 months to 16 years was big and makes the evidence unreliable. In another small study it was demonstrated that the IVC diameter during forced expiration is 4-5mm smaller in transient responders in trauma compared to good responders. [50] Dipti et al.[51] demonstrated in a meta-analysis of 5 studies with a total number of 275 patients, that IVC diameter is consistently low in patients with hypovolaemic shock when compared to euvolaemic patients. No exact diameter was identified as a cut off point for shock. A correlation between IVC diameter, collapse and right atrial pressure has been suggested. Otto suggested a correlation between the IVC diameter and the actual right atrial pressure and demonstrated it in table 4[63]. This table is based on robust evidence and will need to be tested to evaluate its clinical sensitivity and specificity.

The consensus in all these studies is that the IVC volume is smaller in patients with dehydration. In patients with fluid overload and congestive cardiac failure, the IVC diameter seemed to be higher in most patients in a recent study, but they suggested that the most accurate method to confirm fluid overload was to look at respiratory variation of the IVC diameter.[52]Most of the recent studies investigate IVC collapsibility index. This is described as the objective difference between the IVC diameter at the end of inspiration and the end of expiration.

The collapsibility during inspiration is calculated and expressed as inferior vena cava collapsibility index (IVC-CI). The exact method and calculation of IVC-CI is described in methodology. IVC-IC of more than 50% is consistent with a CVP of less than 8cm water with sensitivity of 91% and specificity of 94%[53], and may indicate hypovolaemic state. Various studies have been done to determine the accuracy and the significance of IVC-CI. (Table 3) Unfortunately most of these studies are small and only observational. No randomized controlled or blinded studies were performed. No consensus was reached on the exact area where the IVC-CI should be measured. Most studies refer to an area 3cm below the right atrium or one to two cm below the hepatic vein. The site we used to measure IVC-CI in this study is discussed in the methods. The EP performed inferior vena cava collapsibility index (IVC-CI) has similar accuracy when compared to radiologist performed ultrasound[54].

Reference	Methods	Results	Comments
De Lorenzo et.al.[55] 2011	Unblinded prospective single centre observational study comparing IVC diameter with CVP measured in three different areas. n=72	Poor correlation between CVP and IVC diameter. No collapsibility index calculated.	Best view to use is longitudinal sub-xiphoid to measure IVC diameter
Nagdev et.al.[53] 2010	Prospective observational study comparing IVC-CI in comparison to CVP measurement n=73	CI >50% associated with CVP <8 sensitivity 91% and specificity 94%	If CVP low, good correlation to IVC-CI of more than 50%
Wallace et.al.[56] 2010	Prospective observational study comparing IVC collapsibility at three different sites on healthy volunteers. N=39	Collapsibility similar at level of renal veins and 2cm caudal to hepatic vein.	Level to measure is between 1 and 2cm below hepatic vein
Blehar et.al.[52] 2009	Prospective observational study to demonstrate respiratory variation of IVC diameter in patients with congestive cardiac failure. N=46	15% or less collapsibility indicates CCF with sensitivity of 92% and specificity of 84%	IVC-CI good to indicate CCF
Brennan et al[57] 2006	Prospective observational study of haemodialysis patients pre and post dialysis, comparing dry weight, IVC-CI and IVC diameter n=89	Poor correlation between IVC-CI and dry weight and fluid status of patients	IVC-CI preferred method of fluid assessment, but not very good on its own.
Sefidbakht et.al[58] 2006	Prospective observational study comparing IVC-CI in shocked and non-shocked trauma patients n=88	IVC-CI significantly higher in shock group, 27% vs20%	27% IVC-CI does not correlate well with other studies
Barbier et.al.[59] 2004	Prospective clinical trial comparing IVC-CI in hypovolaemic septic patients before and after fluid bolus of 7ml/kg. N=23	IVC collapsibility index (IVC-CI) of 18% or higher is indication for fluid boluses.	Small study, collapsibility index is the same as CI.
Feissel et al.[60] 2004	Prospective clinical trial comparing IVC-CI in ventilated septic shock patients before and after 8ml/kg fluid bolus n=39	IVC-CI of 12% or higher allowed for identification of responders with positive and negative predictive values of 93% and 92%	IVC-CI good measure to predict fluid responsiveness.
Kircher et.al.[61] 1990	Retrospective observational study comparing right atrial pressure with IVC-CI as performed by cardiologists in ICU n=83	For CVP more than 10, IVC-CI of less than 20% is 100% specific.	IVC-CI very good for fluid overload if less than 20% collapse
Moreno et.al.[62] 2004	Prospective observational study to determine right ventricular function. 3 groups compared, normal, RV failure and cardiac disease but normal RV	Best correlation between IVC-CI and RV failure; gives low CI.	IVC-CI good to indicate increased RV pressure or fluid overload.

Table 3: Literature review of inferior vena cava collapsibility index

IVC diameter (cm)	Respiratory collapse	RA pressure(mmHg)
<1.5	Total collapse	0-5
1.5-2.5	>50% collapse	5-10
1.5-2.5	<50% collapse	10-15
>2.5	<50% collapse	15-20
>2.5	No collapse	>20

Table 4: Central venous pressure by ultrasonography of the inferior vena cava.[63]. IVC =inferior vena cava, RA right atrium

Even though the studies presented are not level one evidence, and various different outcomes were noted, it is clear that there is some level of correlation between the IVC evaluation with EUS, the measured CVP and hydration status of patients. An audit done locally and presented at the EMSSA emergency medicine conference in 2011, showed that the correlation between IVC-CI and CVP measurement is very poor and can only be accurate in the extremes of severe dehydration or severe fluid overload.[64] There was a better correlation between a high CVP and low IVC-CI fluid overloaded patients than low CVP and high IVC-CI in dehydrated patients. Whenever one of these measurements are interpreted by the clinician, it is important that he/she understands the physiology of the patient as well as any underlying abnormality such as valvular disease or cor pulmunale. In the case of IVC-CI the value lies in the extremes of abnormality. If the collapsibility index is more than 50% it is likely that the patient is dehydrated. If the IVC-CI is closer to 0, it is likely that the patient is in RV failure, has valvular disease or cor pulmunale. CVP measurement is inaccurate as a single measure to evaluate hydration status.[65] Marik et.al. described CVP monitoring as completely inaccurate and even respiratory variation was of no use to assess hydration state in ICU patients. The correlation between CVP and IVC-CI is poor as well. Why then are we comparing one technique of volume assessment to another that is deemed inaccurate and recommended not to be used?

A definitive review to demonstrate the clinical use of CVP to assess preload in patients was published in 2006.[66] The author explains that the CVP measured value reaches a plateau where cardiac output is optimal and an increase of fluid volume will cause no change in this value. Cardiac output will also not increase. It is recommended that the CVP measurements are interpreted in combination with other methods of determining cardiac output such as venous oxygen saturation or pulse wave assessment. With careful consideration of individual patient pathology and a good understanding of the complex physiology, the CVP can still be very helpful in assessing the patient's hydration status.

The safest conclusion is to use IVC-CI as an adjunct to clinical findings, history and index of suspicion to make a final call on the hydration status of a patient. Due to the complex and dynamic nature of the physiological compensation for all states of haemodynamic instability, it is difficult to envisage a single gold standard parameter to solve this problem. Because of its non-invasive nature and immediate availability as a bedside examination, EUS examination with assessment of IVC-CI can give valuable information about the patient's hydration status and cardiac function.

1.1.3 FAST views (Morrison's pouch)

Focussed assessment sonography in trauma (FAST) consists of four basic views and is used to detect the presence of free fluid in the pericardium, peritoneum and inter pleural spaces. The FAST scan is included into the HI-MAP protocol in order to identify other potential areas of volume loss. The method of performing a FAST scan is described in detail in the methodology section of this paper. FAST scan was particularly designed for trauma patients in order to identify the presence of free fluid in the peritoneal cavity, pericardium and pleural spaces. The binary questions are:

- Is there free fluid in the peritoneum? Yes or no
- Is there free fluid in the pleural cavity? Yes or no
- Is there free fluid in the pericardium? Yes or no

One study in KwaZulu-Natal showed a sensitivity of 81% and specificity of 100%[67]for detecting free fluid in the abdomen, pericardium and pleural cavities. In one study FAST shows a reduction in time to diagnosis and an increase in survival rate of patients with penetrating cardiac injury[68].It leads to faster time to the operating theatre, reduction in CT scans and improves patient outcome[69]. The three abdominal views of FAST (hepatorenal, splenorenal, pelvic) are helpful in finding free intraperitonial fluid of as little as 250ml.[70]Although the type of fluid cannot be identified, in patients with undifferentiated hypotension, a positive FAST view may indicate intra-abdominal pathology like ectopic pregnancy (blood) or peritonitis (purulent fluid). In non-trauma patients the FAST scan should have similar sensitivity and specificity for detecting free fluid in the above mentioned areas.

The FAST scan has been included in most types of EUS assessment of volume status in patients. (Table 1) Even though this scan does not assess the volume status directly and has not been tested in non-trauma patients, it can still add valuable information and make the final diagnosis more accurate. Potentially it could also lead to further investigations such as CT scan or formal radiologist performed abdominal ultrasound.

1.1.4 Aorta views and abdominal aortic aneurism (AAA)

Detecting abdominal aortic aneurism (AAA) is usually done by CT arteriogram of the abdomen in a patient with classic signs of a leaking aneurism, such as severe back pain, low blood pressure and a pulsating abdominal mass. Unfortunately almost 60% of AAA will not be found until the patient presents with a rupture and in shock.[71] EP performed abdominal scans for the detection of AAA has shown sensitivity and specificity of close to 100%. A literature review was done in 2006 and reported on four studies performed by EP's in the United States and Australia.[72] In all four the studies, the aorta was measured by EP using ultrasound at the bedside. It was measured at three different sites: at the superior mesenteric artery, renal artery and the aortic artery bifurcation.[73] [74] [7576] In all 4 these studies the diameter of an AAA was defined as larger than 3cm at any area of the abdominal aorta. In Knaut et.al. measuring the aorta in the longitudinal plane was the most accurate method, but axial plane measurement was proven to be accurate enough. The population in all these studies were convenience samples and only in one study did they investigate symptomatic patients with abdominal or lower back pain over the age of 55 years. In the other three studies they screened patients for AAA even if there were no indications. A weakness in all these studies was that all the patients in whom they could not visualize the aorta, were excluded from the study population. In all the studies the accuracy of the ultrasound examination was confirmed with the gold standard of CT angiogram. The general conclusion from this literature review is that EP's are accurate in identifying AAA with EUS examination if they can visualize the aorta. In the undifferentiated unstable patient, visualizing the aorta could prove problematic due to bowel gas, body habitus or the inability of the patient to lay supine.

Abdominal aorta diameter of more than 3cm in any abdominal view is diagnostic of an aneurism and more than 5cm is high risk for rupture[77].A diameter of more than 1.5cm in the iliac arteries is suggestive of an aneurism. Detection of abdominal aorta aneurism (AAA) with emergency ultrasound has a positive predictive value of 93% and a negative predictive value of 100% when performed by emergency care practitioners.[71] Ultrasound in the Emergency Centre reduces time to diagnoses of AAA significantly and reduces risk by getting patients into the operating theatre sooner[78]. This ultimately reduces mortality and morbidity.

The importance of including this scan into the HI-MAP protocol is that people with ruptured AAA can present with shock as the only symptom. Less than half of patients presenting with ruptured AAA presents without the classic clinical triad of pain, hypotension and pulsating abdominal mass.[79] This scan is easy to perform and can be used to make a fast and accurate diagnosis of AAA.

1.1.5 Pneumothorax

The scan for pneumothorax is usually part of the extended FAST[18] examination (EFAST) Pneumothorax can be detected by ultrasound using two views and will be described in detail in the methods section of this document. The diagnosis of pneumothorax with emergency ultrasound has showed higher sensitivity over chest X-ray (48.8% versus 20.9%) but still very low sensitivity over all[80]. A meta-analysis done in 2011 included a total of 20 studies where sensitivity and specificity was calculated for the detection of pneumothorax. In this study the pooled population included trauma and critically ill non-trauma patients[81]. The ultrasonographers were also a combination of intensivists, radiologists, cardiologists and EP's. The pooled results showed a sensitivity of 88% and specificity of 99% when compared to CXR. It also proved that ultrasound is cheaper, faster than and almost as accurate as X-ray and also has the benefit of no radiation to the patient. It can be performed by the EP at the bedside of the patient. It is however operator dependant and the studies suggest that experienced ultrasonographers or radiologists could get better results and practitioners with less experience can be less accurate.

It could therefore guide emergency care practitioners to confirm a pneumothorax in an unstable patient. It has to be remembered though, that the presence of a pneumothorax could be identified with ultrasound, but that it is difficult to determine the size. A combination of clinical findings and a suspicion of pneumothorax being a causal factor in the unstable patient, must guide the clinician to an appropriate intervention such as the insertion of an intercostal chest drain.

1.1.6 Deep Venous Thrombosis (DVT)

Even though originally included in the RUSH protocol, the DVT scan was not included in this study. Scans for DVT was only done when there was a high index of suspicion of pulmonary embolism as diagnosed by cardiac scan, IVC assessment and clinical suspicion based on the Wells criteria for pulmonary embolism. Documentation of DVT scans were not included in the departmental log book for the HI-MAP scan, and were documented elsewhere.

1.1.7 Volume assessment by Emergency Ultrasound – the combination of all the scans

A lot of EUS scans have been described in the literature. (Table 1) All the scans listed in this table are review articles and give in depth descriptions and literature reviews of how to perform the scans and possible accuracy and efficacy. The evidence for using a combination scan to determine fluid status is scanty. (Table 5) In 2009, Marik et.al. published a review article and discussed all the latest evidence in relation to monitoring hydration state in patients.[82] His suggestion was that there is no single measuring technique that could be used in isolation to accurately assess hydration status in a human. A combination of clinical examination, continuous pulse pressure monitoring and stroke volume assessment is the cornerstone of good volume assessment in the ICU. Cardiac echo and IVC measurement compliment the above mentioned methods

Reference	**Methods**	**Results**	**Comments**
Carr et.al.[83] 2007	Prospective observational study by ICU doctors using IVC-CI and cardiac contractility to determine hypovolaemic or not hypovolaemic. Expert clinical assessment –"gold standard"	Volume assessment with Ultrasound the same as clinical examination by expert and CVP monitoring	Only look at IVC and cardiac contractility, no other aspects like FAST included
Jones et. al.[27] 2004	Randomized controlled trial comparing diagnostic accuracy in undifferentiated shock with early EUS and delayed EUS. Used the RUSH protocol	In early EUS group diagnosis was accurate in 80% vs. only 50% in delayed group	Early goal directed ultrasound in shocked patients improves the accuracy of physician diagnosis during early assessment.

Table 5: Literature review of complete volume assessment scans including cardiac contractility and IVC-CI

2 Aim

The aim of this study is to demonstrate the use of the emergency practitioner performed HI-MAP scan to determine the cause of haemodynamic instability in critically ill patients in the EC and aid in early diagnosis.

3 Objectives

The objectives of this study are to:

- Describe the type of ultrasound scans performed as part of the HI-MAP scan and discuss the evidence
- Demonstrate how the use of ultrasound can improve the accuracy of the final diagnosis compared to provisional diagnosis.
- Describe the utility of HI-MAP scan in the emergency centre
- Demonstrate that the HI-MAP scan can reduce time to diagnosis
- Make recommendations for future use of this modality in South Africa

4 Methods

4.1 General Methods

This is a cross sectional retrospective descriptive study of HI-MAP scans performed on patients who were admitted to the emergency centre resuscitation unit (ECRU) at Ngwelezane Hospital from 1st January 2010 until 30th November 2011. Scans were performed by two emergency care practitioners: a Chief specialist in emergency medicine, also head of department and level 2 EUS instructor and a grade 3 medical officer with the same level of experience in EUS. Only scans performed by these two doctors were included in the study as they were the only qualified emergency sonographers in the department at the time.

A General Electric Logiq P5 Ultrasound Machine with 5MHz curvilinear transducer was used to perform all the scans. Scans were only performed if one of the two investigators were on site. If patients were admitted during their absence, a scan was performed when the investigators arrived at the EC and only if the patients were still unstable. When patients were stabilized, scans were not included in this study.

Perera et. al.[23] described a sequence for the RUSH-scan which follows the HI-MAP acronym. In the departmental guidelines we drew up a protocol for the use of the HI-MAP scan based on the RUSH sequence. (Appendix 1) After triage was performed in the EC using the South African Triage Score (SATS) [84], patients were admitted to the resuscitation area if they were deemed unstable. Patients were deemed unstable if they fulfilled the criteria for immediate treatment according to SATS. Clinical examination was immediately followed by the HI-MAP scan after which a provisional diagnosis was formulated and treatment started. Inclusion criteria were determined after data collection was complete.

As part of the departmental protocol, the aim was to scan patients as soon after admission as possible, after basic history and physical examination were completed. Treatment was not delayed as a result of performing any scans.

4.2 Data collection

All scans were logged on a password protected computer database, set up to audit the use of ultrasound in the EC. Specific forms for different types of scans were drawn up including the HI-MAP scan (Appendix 2). Information recorded, included: Age, blood pressure, respiratory rate, pulse rate, clinical findings, provisional diagnosis, scan findings, time of admission, time of scan, provisional diagnosis, final diagnosis and final outcome after treatment as improved or died. The Glasgow Coma Scale (GCS) was only recorded if it was abnormal. If patients were confused, the GCS was documented as 14/15. If the diagnosis was confirmed by any other means after the HI-MAP scan was performed, it was also documented. Provisional diagnosis was documented after admission and was solely based on history and clinical findings. A final diagnosis was documented after the HI-MAP scan was performed based on history, clinical findings and the additional information obtained from the HI-MAP scan.

All imaging performed on patients were documented on the departmental database and discharge summary system. (Fig 3) This indicates that at least one or more ultrasound scans are performed per day in the EC. This includes all types of scan like FAST, HI-MAP, vascular access and nerve blocks. These statistics does not include the minors area, or casualty as it is known in many South African hospitals.

4.3 Study Population

Ngwelezane hospital is situated in northern KwaZulu-Natal, about 160 km north of Durban. It is rated in the South African system as a regional and tertiary hospital. Due to its location and distance from any metropolitan or big city centre, it has to fulfil the function of regional as well as tertiary level care. It has 22 district hospitals in its feeding area that refers patients for tertiary and district level care. The area, known as area 3, has a total of 3.5 million people and stretches from Eshowe in the south to the border of Mozambique in the north. It has 554 beds and has a turnover of about 75000 patients per year. It has a combined surgical, medical and trauma emergency centre that sees on average 8-10 new critical care admissions per day.

The majority of admissions are surgical and trauma at 60 -70% per year and medical cases 35-40%. (Fig 4) This means that 3-5 patients per day are acute medical admissions. The admissions to the resuscitation unit (RU) are all critically ill patients that need resuscitation as part of treatment. No elective admissions are done to the RU. At Ngwelezane Hospital, local policy only allows for children under the age of 12 to be treated in the paediatric department. Thus all patients 12 years old and above, are treated at the adult EC. A great variety of diagnosis is seen in the EC. We do not include paediatric, gynaecology or obstetrics patients as they have separate emergency centres.

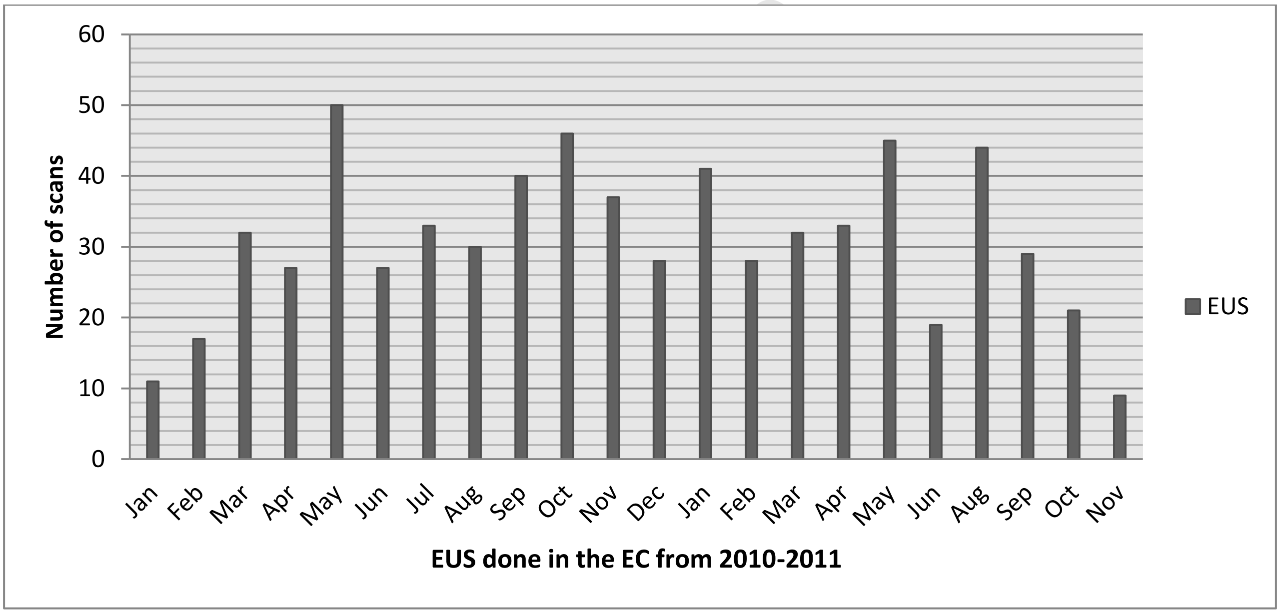


Figure 3: Emergency ultrasound scans performed per month in the resuscitation unit during the study period. This graph does not include scans performed in the minor area.

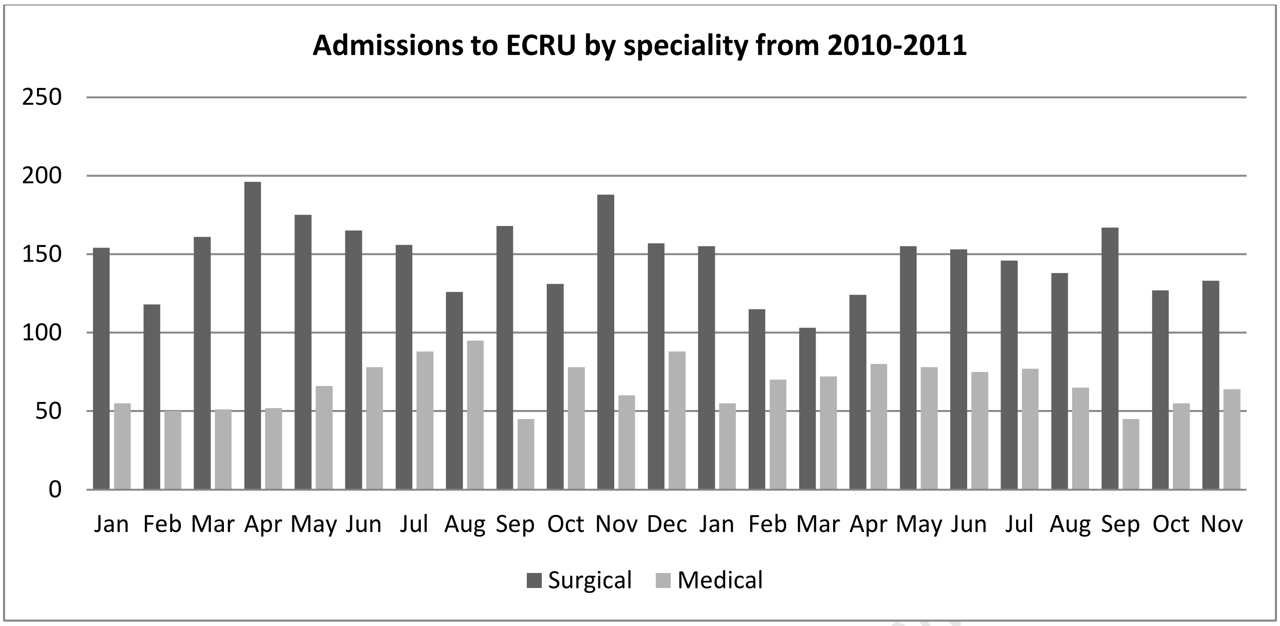


Figure 4: Admissions to the emergency centre at Ngwelezane hospital from January 2010 to May 2011, divided into surgical and medical. Adapted from the departmental database. Surgical cases include trauma. Paediatric, gynaecology and toxicology cases were not included in this graph.

4.4 Performing the HI-MAP scan

The HI-MAP scan is performed with the patient lying in a supine position. The order in which the views were performed was not important, as long as all views were done and all the necessary information gathered. Perera et.al[23] recommends that the HI-MAP sequence be followed.

4.4.1 Heart or cardiac views

In our study we compared the ventricle size by qualitative observation and only commented on the ratio if it was obviously normal, i.e. RV smaller than LV or obviously abnormal, RV equal or bigger than LV. If there was suspicion of PE and the patient was stable enough, CT angiogram would be done.

The following views were used:

- Sub-xiphoid view (Fig 5)
- Parasternal long axis view (Fig 6,7)

- Apical four chamber view (fig 8)

The sub-xiphoid view was used as the primary view to look at cardiac contractility, right ventricular filling and pericardial effusion. If this view could not be obtained or did not give clear answers to these questions, the parasternal long axis view and the apical four chamber view were used to determine left ventricular contractility and pericardial effusion. The particular views used to determine the contractility and effusions were not documented.

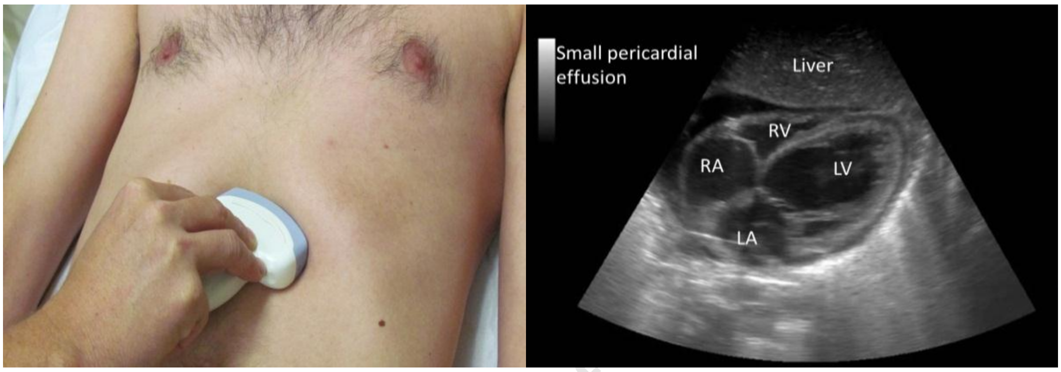


Figure 5a **Figure 5b**

Figure 5: Sub-xiphoid view; probe position figure 5a and sub-xiphoid ultrasound view right; LV left ventricle, RV right ventricle, LA left atrium, RA right atrium

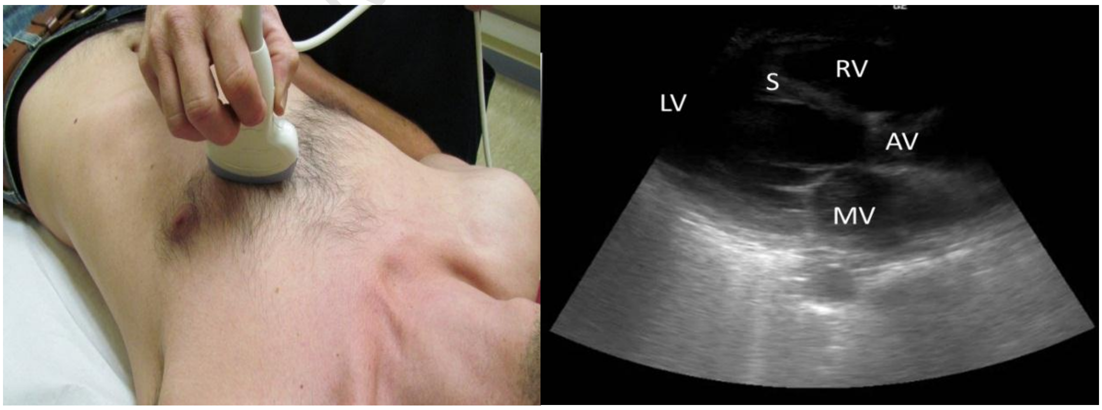


Figure 6a **Figure 6b**

Figure 6: Parasternal long axis view; probe position figure 6a, and parasternal long axis ultrasound view in figure 6b, LV left ventricle, RV right ventricle, AV aorta valve, MV mitral valve, S inter ventricular septum

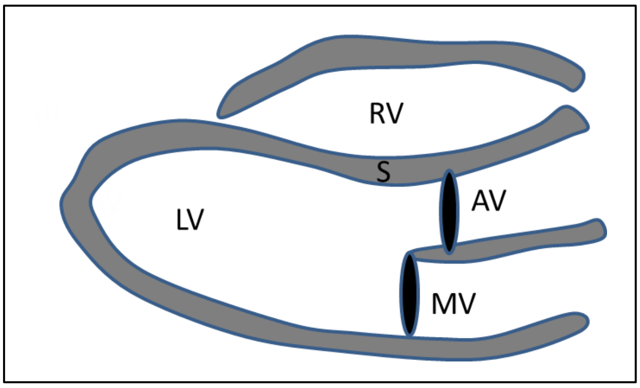


Figure 7: A schematic illustration of the parasternal long axis view in figure 6, LV left ventricle, RV right ventricle, AV aorta valve, MV mitral valve, S inter ventricular septum

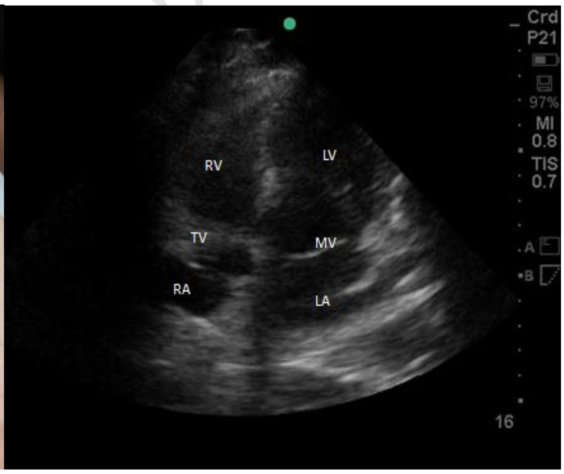


Figure 8a **Figure 8b**

Figure 8: Apical four chamber view; probe position figure 8a and ultrasound view figure 8b; RV right ventricle, LV left ventricle, TV tricuspid valve, MV mitral valve, RA right atrium, LA left atrium

4.4.2 Inferior vena cava collapsibility index (IVC-CI)

The IVC was visualized by using the sub-xiphoid longitudinal view with the curvilinear 5MHz transducer. (Fig 10) The diameter was measured using M-mode. It was measured 1 cm below the diaphragmatic notch or 3 cm below the cardiac angle (entrance to right atrium). (Fig 9 and 10) The diameter during inspiration and expiration were documented and IVC-CI was calculated with the following formula:

IVC-CI = [1-IVC inspiration/IVC expiration] x 100

IVC inspiration and expiration refer to the diameter of the IVC. IVC-CI was then documented as a percentage collapse.

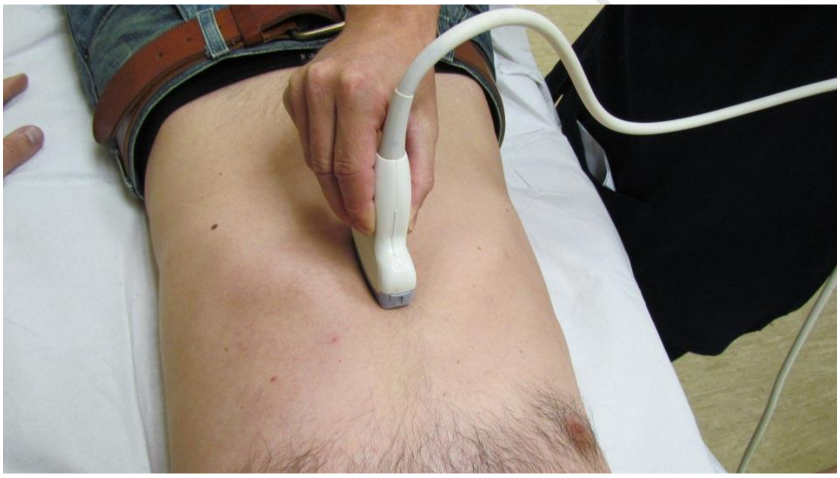


Figure 9: Sub-xiphoid longitudinal view to visualize the IVC in its length

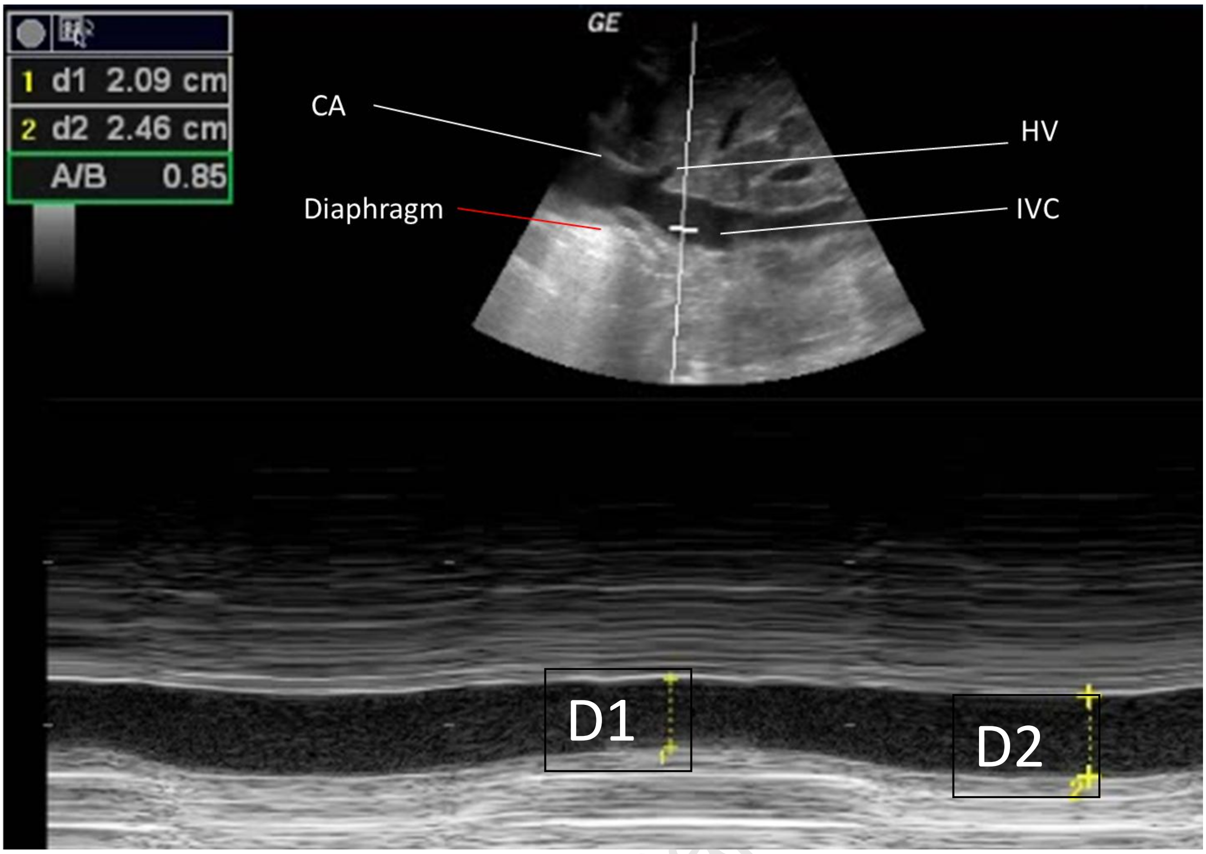


Figure 10: Ultrasound view of the IVC in M-mode; IVC inferior vena cava, HV hepatic vein; d1 depicts the diameter of the IVC during inspiration and d2 the diameter during expiration of the patient. IVC-CI in this example is calculated as follows: IVC-CI = [1-IVC inspiration/IVC expiration] x 100 = [1-2.09/2.46] x 100 = 15% collapsibility.

4.4.3 Morrison's pouch or FAST views

The FAST views were performed and the presence of free fluid was noted and documented:

- Right upper quadrant or hepato-renal view (Fig 11)
- Left upper quadrant or spleno-renal view (Fig 12)
- Supra pubic longitudinal and transverse views (Fig 13)

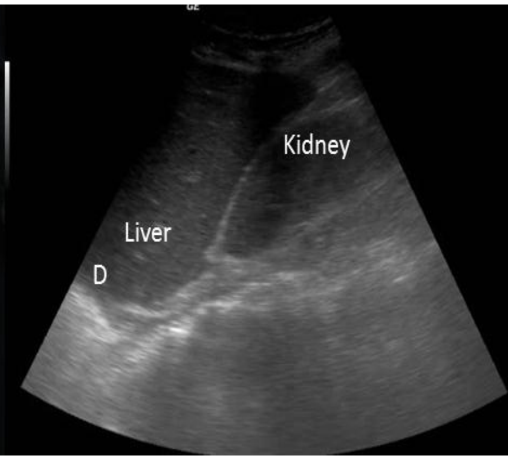


Figure 11a **Figure 11b**

Figure 11: right upper quadrant view, Figure 11a: probe position. Figure 11b: ultrasound view. D diaphragm. Free fluid is usually visible in Morrison's pouch between kidney and liver.

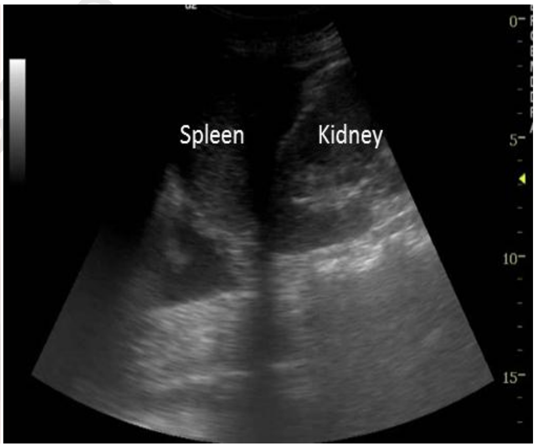


Figure 12a **Figure 12b**

Figure 12: Left upper quadrant view. Figure 12a : Probe position, Figure 12b: ultrasound view. Free fluid usually observed around spleen or between kidney and spleen

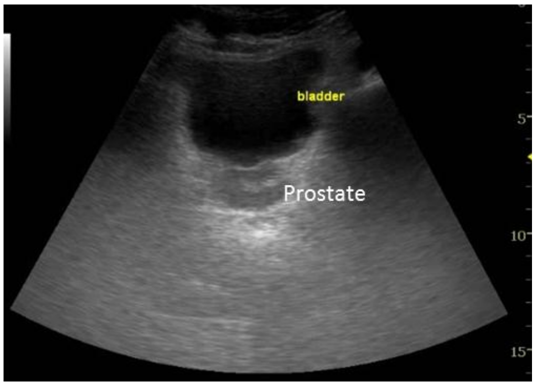


Figure 13a **Figure 13b**

Figure 13: Supra pubic transverse view. Figure 13a: probe position, Figure 13b: ultrasound view Free fluid usually observed posterior to bladder.

4.4.4 Abdominal Aortic Aneurism (AAA)

The aorta was visualized at three different levels on transverse sections.

- Sub-xiphoid
- At the level of the renal arteries
- At the bifurcation or iliac arteries

The aorta was visualized in the transverse plane as well as the longitudinal plane. (Figure 14) The measurements were taken from the outer walls of the aorta and only the widest of the three diameters was documented. The longitudinal view was also obtained and the diameter measured at the level of the superior mesenteric artery (SMA), renal arteries and at the bifurcation, also from the outer walls. The diameter of more than 3cm was defined as an AAA.

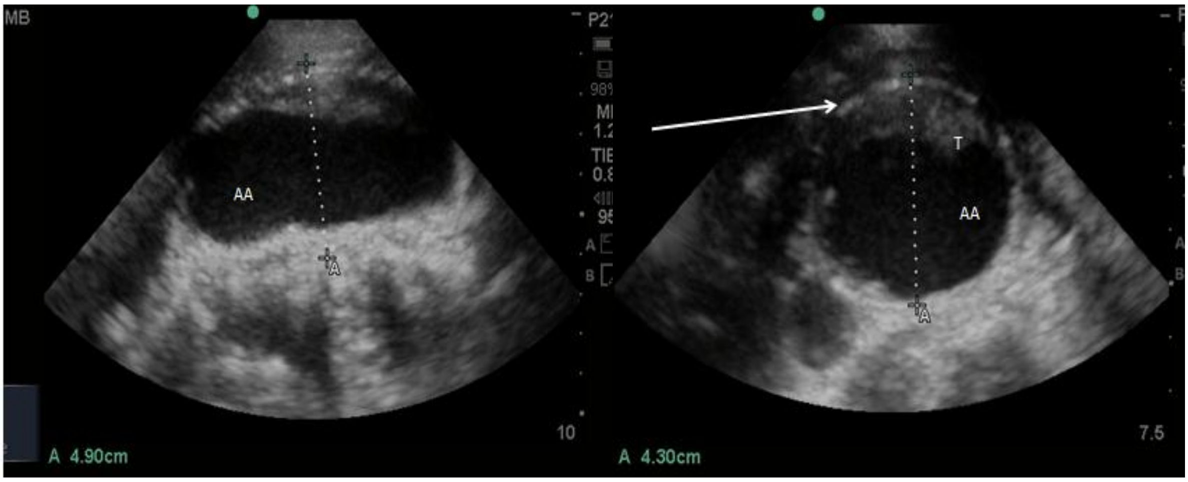
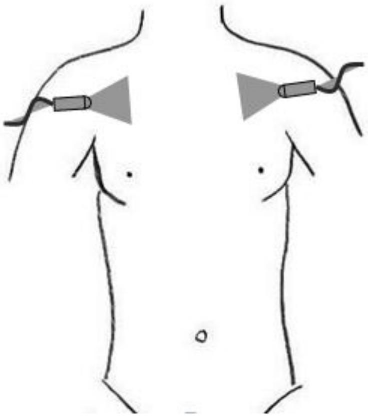


Figure 14a **Figure 14b**

Figure 14: Figure 14a demonstrates a longitudinal view of the abdominal aorta at the level of the renal arteries. The diameter in this case is 4.9cm. Figure 14b demonstrates the transverse view of the aorta at the same level. Note the slight difference between the diameters measured in the two views. In this patient a diagnosis of abdominal aorta aneurism was made. AA abdominal aorta, T thrombus in the aorta.

4.4.5 Pneumothorax

The scans were performed with the same curvilinear probe, second inter-costal space, mid clavicular line bilateral. Movement of the pleura is observed as a “line of ants” or M-mode is used to identify a pneumothorax. Usually the curvilinear or the linear transducer can be used. Depth is set to minimum and a view obtained so that two rib shadows are visible with the underlying soft tissue, intercostal muscles and the pleura which is usually hyperechoic or white. When M-mode is used to determine the presence of a pneumothorax, the ”seashore sign” or “waves on beach” should be identified to exclude the diagnosis.(Figure 15c and 15d)



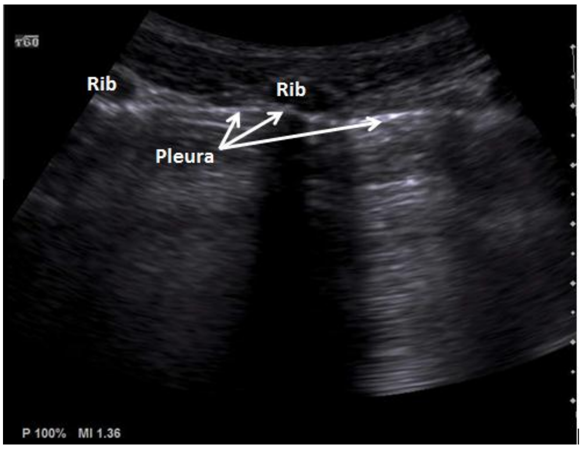


Figure 15a **Figure 15b**

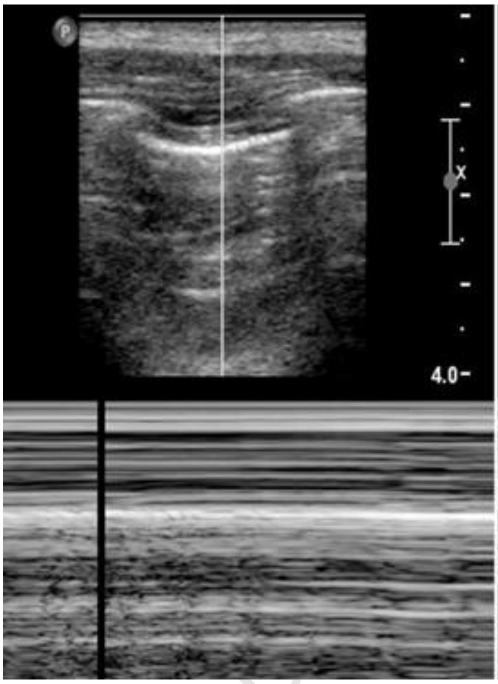


Figure 15c **Figure 15d**

Figure 15: The views for pneumothorax. Figure 15a shows probe position. Figure 15b shows a static image where the pleura is visible as a bright white line below the ribs. Figure 15c shows pleural assessment in M-mode with a negative pneumothorax and figure 15d a positive pneumothorax. Note the "stratosphere" sign: beach in the foreground with smooth sky above. In the positive pneumothorax in figure 15d the deeper area appears smooth and less grainy. Picture: Courtesy Dr Mike Wells, EMSSA ultrasound course.

4.5 Inclusion criteria

All haemodynamically unstable patients who received a HI-MAP scan during the study period and fulfilled criteria set by the investigators were included. Patients were scanned if they fulfilled the criteria for immediate treatment according to SATS. Once the data was collected, one or more of the following criteria had to be met for inclusion to analysis:

- Systolic blood pressure more than 180 or less than 100
- Diastolic blood pressure more than 110 or less than 60
- Pulse rate higher than 100
- Respiratory rate of more than 29 or less than 9
- Glasgow coma scale less than 14 not due to head injury

4.6 Exclusion criteria

- Trauma patients
- Patients under the age of 12 years
- Patients in cardiac arrest
- Ventilated patients

4.7 Data Analysis

Data was entered into a Microsoft Access database and stored in Microsoft Excel as a linked table. Data was processed using Microsoft Excel and Analyse-it™. Data was scrutinized to ensure that inclusion criteria were met. Population statistics were performed using Analyse-it™ with simple descriptive statistics.

Provisional diagnosis and final diagnosis had to be categorized into broader diagnostic categories to simplify the analysis and to better demonstrate the fluid status of the patient as overloaded, normal or depleted. It was categorized into fluid overload, cardiogenic shock, hypovolaemic shock, septic shock, and undifferentiated shock. (Table 6)

Time of admission and time of scan were documented accurately but duration of the scan and time of final diagnosis were not measured and documented. Therefore only the time between admission and scan was used for analysis.

4.8 Data Management

Data was kept on a password locked computer database. Only the two trained emergency care practitioners performing emergency ultrasound scans had access to this database. All patient information is documented anonymously with hospital numbers for future reference. All hard copies of the database are kept in locked cupboard in the supervisor's office.

4.9 Literature review

A literature search was performed using Wolters Kluwer OvidSP, Athens Journals, Cochrane library of systematic reviews, Google, BestBet and Elsevier Journals and PUBMED. The following MESH terms were used: Emergency Ultrasound, Bedside ultrasound, point of care ultrasound, volume status and Ultrasound, ultrasound and shock, cardiac ultrasound in shock, cardiac contractility and ultrasound, pericardial effusions and ultrasound, cardiac tamponade and ultrasound, cardiac echo and shock, cardiac echo and volume status, rapid ultrasound in shock and hypovolaemia (RUSH), Abdominal and Cardiac Evaluation with *Sonography* in Shock (ACES), inferior vena cava collapsibility index (IVC-CI), IVC measurement and Ultrasound, Central venous pressure (CVP) accuracy, ultrasound vs. CVP, abdominal ultrasound and shock, abdominal aortic aneurism and ultrasound, Pneumothorax and ultrasound, undifferentiated shock, accuracy of emergency ultrasound, Focussed ultrasound, cardiac index ultrasound, haemothorax ultrasound diagnosis.

Papers were identified in order of importance as follows:

- Randomized controlled trials
- Meta-analysis
- Systematic reviews
- Observational studies
- Review articles
- Case studies

Specific studies were identified for each individual step of the HI-MAP scan as well as combinations of the ultrasound steps such as cardiac contractility with IVC-CI. All studies had to address the use of ultrasound to determine hydration status of patients, causes of shock or causes of cardiac dysfunction. Studies performed by EP's in the EC to assist with diagnosis were particularly searched for. Critical appraisals of each study were performed by the author and consequently cross referenced to find further appropriate studies. The studies were filed and tabulated in separate tables as demonstrated in section 1.1

4.10 Ethical considerations

The study has been approved by the Ngwelezane ethics committee as well as the DRC of the Division of Emergency Medicine of the University of Cape Town. Ultrasound is used in the Emergency Centre at Ngwelezane Hospital on a daily basis and did not involve altering any treatment protocols. No treatment was delayed for the purpose of performing scans.

Assigned Diagnosis	Diagnosis as documented by attending doctor
Fluid overload	Congestive Cardiac failure (CCF) Right ventricular failure Left ventricular failure Cor pulmunale Acute valve failure Cardiogenic pulmonary oedema Cardiomyopathy with failure Acute myocardial infarction with failure High output cardiac failure Renal failure and fluid overload Fluid overload
Cardiogenic shock	Cardiogenic shock Dilated cardiomyopathy and shock Cardiac arrhythmia Cardiac tamponade Pulmonary embolism
Hypovolaemic shock	Gastro enteritis Acute gastro intestinal haemorrhage Anaphylaxis TB abdomen and dehydration Bowel obstruction and dehydration Diabetic keto-acidosis no sepsis
Septic shock	Acute appendicitis Meningitis Sepsis Diabetic keto acidosis (DKA) and sepsis Diabetic foot Perforated bowel Infective endocarditis Septic shock
Undifferentiated	More than one diagnosis No clear diagnosis

Table 6: Diagnosis listed in the first column was assigned to the specific documented diagnosis by the attending doctor

5 Results

5.1 Population

A total of 137 cases were recorded in the database. Four cases were excluded. Two were trauma patients, one did not fulfil the inclusion criteria because all vitals were normal and one was a patient in cardiac arrest and the scan was done after CPR was commenced. A total of 133 cases were included. 51.1% (n=68) were females and 48.9% (n=65) were males. (Table 7) Ages ranged from 14 years up to 90 years. The median age was 48 (SD 40 – 48 CI 96.3%). The mean age was 47.1 years (SD ± 2.9 CI 95%). The population has a positive skewness of 0.27 and a Shapiro-Wilk W test of 0.97 (p= 0.009).

One hundred and seventeen patients (88%) were included based on 2 criteria and 16 (22%) patients based on one criterion only. A total of 118 (88%) patients had a pulse rate of hundred and above. The mean pulse rate of the study population was 120 (±4.1 CI 95%) with a range of 40 to 180. Forty eight patients (36%) had systolic blood pressure of less than 100 and 10 patients (7%) above 180mm Hg. Fifty four patients (47%) had diastolic blood pressure of 60mmHg or less and 11 above 110 mmHg (8%).

		total population	**Males**	**Females**
Age	n	133	65	68
	Mean	47.1	46.8	47.4
	95% CI	44.1 to 50	42.6 to 50.9	43.2 to 51.6
	SE	1.47	2.07	2.11
	Range	76 (14-90)	64 (28-86)	76 (14-90)

Table 7: Age distribution of study population

The respiratory rate (RR) of only 44 (33%) patients was documented in the database. It is a very sensitive vital sign to indicate the presence of shock and metabolic acidosis and was thus included into the SATS. The mean RR was 41 breaths per minute (39.5-44.0 CI 95%). All recorded respiratory rates were above 29 breaths per minute. (Table 8)

The Glasgow coma scale (GCS) was recorded in 26 (20%) cases. In 14 cases the GCS was 14/15, 2 cases 13/15, 1 case 11/15, 2 cases 10/15 and 7 cases were 8 or less out of 15. In all recorded cases the patients were deemed critically ill and unstable at the time of performing the HI-MAP scan.

		Total Population	**Males**	**Females**
N		133	65	68
Pulse rate	Mean	120.0	120.3	119.7
	95% CI	115.8 to 124.1	114.7 to 125.8	113.3 to 126.0
	SE	2.09	2.77	3.15
	Range	140 (40-180)	112 (68-180)	125 (40-165)
SBP	Mean	116.6	118.5	114.8
	95% CI	110-123.2	109.2-127.7	105.1-124.4
	SE	3.34	4.62	4.84
	Range	182 (60-242)	172 (60-232)	182 (60-242)
DBP	Mean	70.6	70.4	70.9
	95% CI	66-75.3	64.3-76.5	63.7-78.0
	SE	2.35	3.05	3.57
	Range	141 (30-171)	92 (30-122)	141 (30-171)
RR	N	44	21	23
	Mean	41.8	43.2	40.5
	95% CI	39.5 to 44.0	39.8 to 46.6	37.3 to 43.6
	SE	1.10	1.62	1.49
	Range	27 (29-56)	27 (29-56)	25 (30-55)

Table 8: Vitals of study population; SBP systolic blood pressure, DBP diastolic blood pressure, RR respiratory rate

5.2 Diagnosis

5.2.1 Provisional diagnosis

The provisional diagnosis was based on clinical findings on initial examination of the patient by emergency practitioner. Fluid overload was the most common diagnosis (n=52, 39%). Fifty of the patients in this group had congestive cardiac failure (CCF) and 2 were in renal failure. (Fig 16) This is significant when compared to the final diagnosis. (Table 9) Out of the 52 patients that were diagnosed with fluid overload, 99% were diagnosed with CCF and only 40 (77%) of those had the same final diagnosis. This means that 33% of the patients initially thought to have CCF, turned out to have another diagnosis. If treatment were initiated on these patients based on clinical skills, the outcome could have been deleterious to these patients.

Septic shock and hypovolaemic shock was second and third with 21 (16%) and 19 (14%) respectively. This was followed by cardiogenic shock (n=16, 12%).Undifferentiated shock accounted for 21 cases (16%). Five cases were given the provisional diagnosis of pulmonary embolism based on history, clinical presentation and index of suspicion.

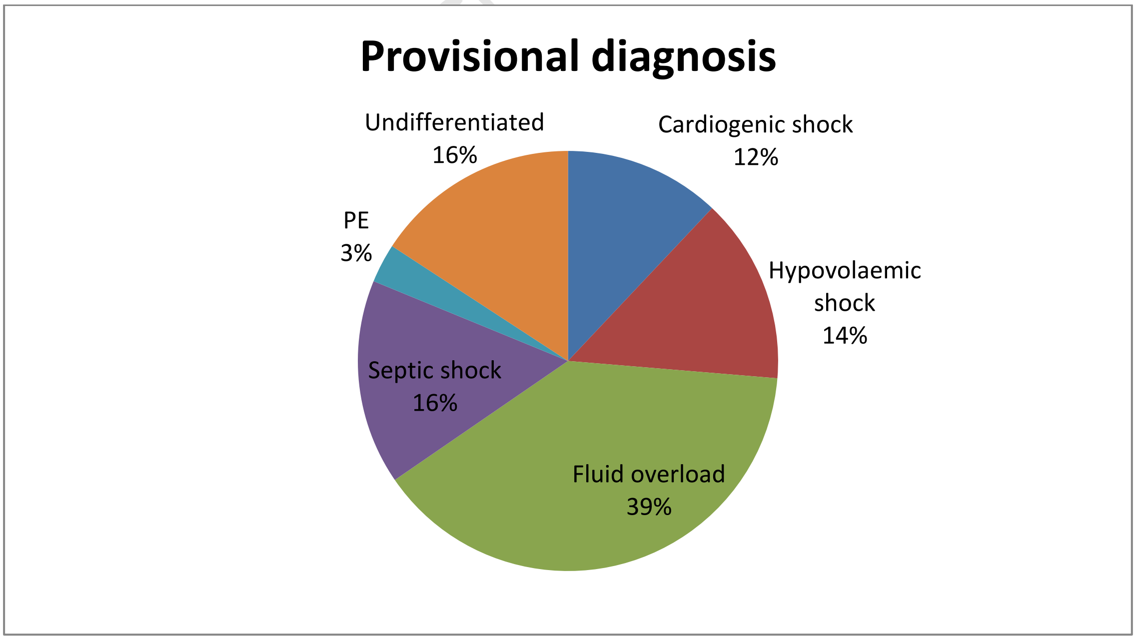


Figure 16: Provisional diagnosis based on clinical examination and history.

5.2.2 Final Diagnosis

The HI-MAP scan was used to assist in the final diagnosis which was based on a combination of clinical findings and other radiological investigations such as CT, x-ray and formal echocardiogram. Fluid overload was diagnosed in 49 (37%) patients. (Figure 17) Forty three of these patients had CCF and the other 6 had fluid overload due to renal failure.

Thirty one (23%) patients were diagnosed with hypovolaemic shock, and 22 patients (17%) with septic shock. Cardiogenic shock was diagnosed in 19 (14%) patients and included four patients with right ventricular collapse and pericardial effusions, thus in cardiac tamponade. Five patients were diagnosed with pulmonary embolism (PE) as a result of the following ultrasound findings:

- Dilated right ventricle
- Dilated right atrium
- IVC-CI of less than 25%
- Poor left ventricle filling
- Hyper dynamic contractility.

Treatment was initiated and diagnosis of PE confirmed with CT scan in all five cases. Final diagnosis was only confirmed in 28 out of the 133 with CT scan, formal echo and laparotomy in a few septic patients. Six patients had unexpected findings on ultrasound and had to be classed as “other” diagnosis. One patient had a mass pressing on the IVC and almost completely obstructed blood flow. This was confirmed with CT scan and biopsy during surgery showed a ganglioma of 3cm by 4cm at the level of the pancreas. The other patient had bowel obstruction with sepsis. Due to excessive bowel gas no proper views could be obtained. A further 4 patients were normovolaemic on USS and diagnosis of CVA was confirmed with CT scan.

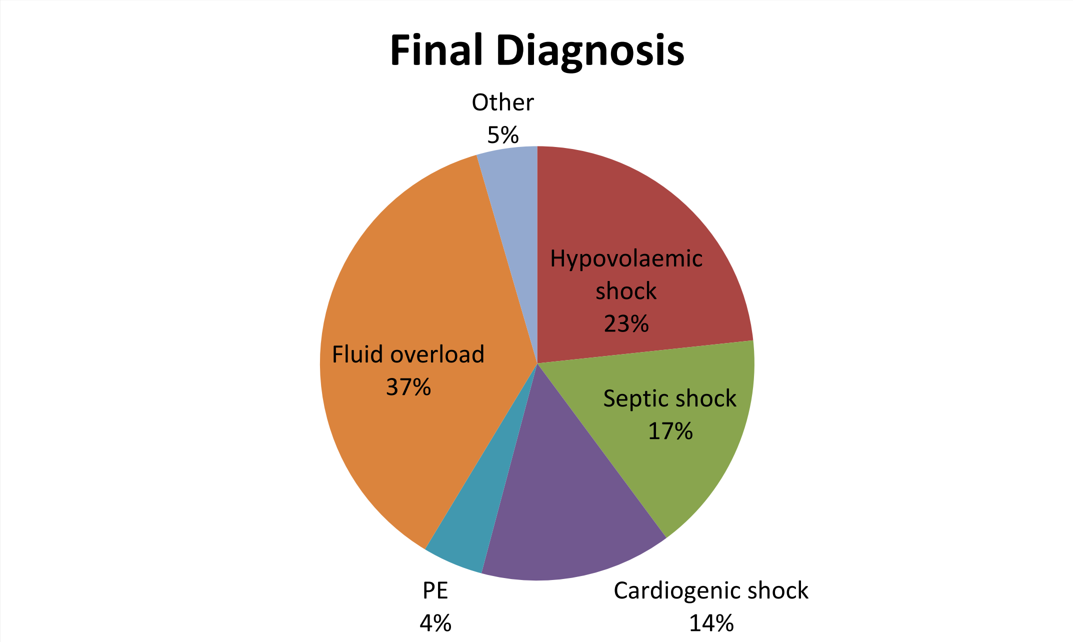


Figure 17: Final diagnosis

5.2.3 Provisional vs. final diagnosis

When looking at provisional and final diagnosis, 65% (n=87) of the provisional diagnosis correlated with the final diagnosis after USS were performed and thus was useful in confirming the diagnosis in these cases.(Table 9) In more than a third of the study population (n=46) ultrasound contributed to making a different diagnosis. In all 21 cases with a provisional diagnosis of undifferentiated shock a final diagnosis could be made after the HI-MAP scans were performed. This diagnosis was solely based on the HI-MAP scan findings. In difficult cases where clinical diagnosis is uncertain, the HI-MAP scan made a proper diagnosis possible in 100%. Eighty nine percent of patients with provisional diagnosis of hypovolaemic shock correlated with the final diagnosis and 67% of patients with septic shock. In 23% of patients initially diagnosed with fluid overload including CCF, the diagnosis was found to be different using EUS and appropriate treatment could be initiated. Even though outcomes were not directly measured in this study and patients were not followed up after discharge from the EC, the question arises whether the patients would have done worse if treated without the HI-MAP results. This demonstrates the need for further research in EUS diagnostics, specifically comparing mortality rates in patients that had HI-MAP scans vs. no ultrasound and conventional diagnostics and treatment.

Diagnosis	Provisional	Final	Final Diagnosis Same	Final Diagnosis Different
Cardiogenic shock	16	19	10(63%)	6(38%)
Hypovolaemic shock	19	31	17(89%)	2(11%)
Fluid overload	52	49	40(77%)	12(23%)
Septic shock	21	22	14(67%)	7(33%)
PE	4	6	3(75%)	1(25%)
Undifferentiated	21	0	0	21(100%)
Other	0	6	0	6(100%)
Totals	133	133	87(65%)	46(35%)

Table 9: A comparison of provisional and final diagnosis; the last two columns demonstrate the number of diagnosis from each specific group that the same or different after compared to final diagnosis.

5.3 Cardiac contractility and IVC collapsibility (Table 10)

In patients with a final diagnosis of fluid overload the majority of patients had poor 53% (n=26) cardiac contractility and IVC-CI was less than 25% in 92% (n=45) of patients, indicating increased preload. Thirty seven percent of this group had normal cardiac contractility and unexpectedly 5 (10%) patients had hyper dynamic cardiac contractility. This means that cardiac contractility as a stand-alone diagnostic tool in patients with CCF and fluid over load is less accurate than IVC-CI. Poor myocardial contractility only occurs with myocardial pathology and will not reveal other causes such as valvular disease. Poor IVC collapsibility of less than 25% is much more accurate in demonstrating a high preload. One of the 5 patients with hyperdynamic cardiac contractility had severe mitral valve regurgitation and another, infective endocarditis with visible valvular vegetations on the basic cardiac views. In 3 patients the hyper dynamic contractility could not be explained, but they all had an IVC-CI of less than 25% which indicated increased pre-load.

In the Cardiogenic shock group 68% (n=13) had poor contractility. Thirteen patients also had IVC-CI of less than 25%. Nine patients had both of these findings. Cardiac tamponade was included in the diagnosis of cardiogenic shock and was diagnosed in four patients based on the following findings:

- Pericardial effusion greater than 1cm
- IVC-CI <25%
- Collapse of right ventricle
- Dilated right atrium

All four patients had normal or hyperdynamic contractility, indicating that the pathology was not in the myocardium, but also had IVC-CI of less than 25% suggestive that there is congestion and increased pre-load. Effusions measured 2cm in 2 cases, 3cm in one and 4cm in the other. They were all started on TB medication after USS guided pericardiocentesis. If cardiac tamponade was excluded from the cardiogenic shock group, 13 out of 15 patients (86%) would have had poor cardiac contractility, indicating that the cardiogenic shock is due to myocardial compromise. One patient had hyperdynamic contractility with IVC collapsibility of 25-50% and a diagnosis of high output cardiac failure was made due to anaemia. Another patient had normal contractility and clinical diagnosis of supra ventricular tachycardia was made based on ECG findings

In the patients with hypovolaemic and septic shock, contractility was hyperdynamic in 79% (n=23) and 86% (n=19) respectively. Hyperdynamic contractility is an equally sensitive finding in septic and hypovolaemic shock. IVC-CI of more than 50% was seen in 83% (n=24) of hypovolaemic patients and 68% (n=15) of septic patients. IVC-CI seems to be a more likely finding in hypovolaemic shock than septic shock and could be explained by fluid loss vs. fluid distribution. Four patients in the hypovolaemic group and 3 in the septic group showed normal cardiac contractility, but all had more than 50% IVC-CI, i.e. intravascular depletion.

Six patients were diagnosed with pulmonary embolism (PE). All of these patients had an IVC-CI of less than 25% with hyperdynamic cardiac contractility in 2 (33%), normal contractility in 3 (50%) and poor contractility in one (17%) case. In all 6 patients the right ventricle and atrium were dilated and in one patient a blood clot was visualized in the right ventricle. Four of the PE cases were confirmed with CT angiograms and one patient died before confirmation could be obtained.

Patients with the diagnosis of fluid overload presented with predominantly poor contractility and IVC_CI of less than 25%.(Figure 18) When combining cardiac contractility and IVC-CI in fluid overloaded patients, 95% of patients had at least one of these findings. (Table 11) In 92% of these patients USS showed IVC-CI of less than 25%, suggesting that this is the most sensitive indicator of fluid overload. Both findings in combination occur in 48% of fluid overloaded patients.

In the septic and hypovolaemic shock patients the predominant findings were hyperdynamic cardiac contractility in 82% of patients and IVC-CI of more than 50% in 76% of patients. When combining these results in the hypovolaemic and septic shock group, 96% of cases had at least one of these findings. (Table 11) Hyperdynamic contractility was found to be more than 80% in both these groups and more than 68% showed CVI-CI of more than 50%, indicating that these are the most helpful signs in this diagnosis. Both findings are present in 62% of patients.

In fluid overloaded and CCF patients the most likely findings are IVC-CI of less than 25% indicating increased preload while hyperdynamic contractility is the most likely finding in hypovolaemic and septic shock

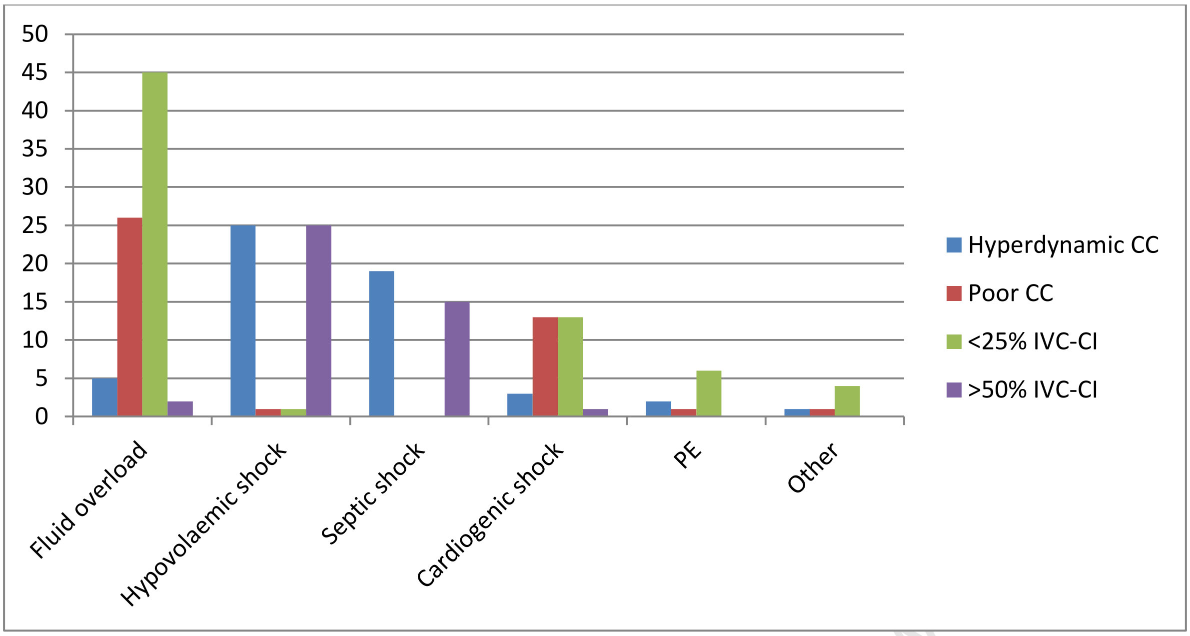


Figure 18: Bar chart to demonstrate the most likely findings of cardiac contractility and IVC-CI in specific diagnostic groups. IVC-CI inferior vena cava collapsibility index, CC cardiac contractility, PE pulmonary embolism

	Contractility			**IVC-CI**				
Diagnosis	**Hyperdynamic**	**Normal**	**Poor**	**<25%**	**25-50%**	**>50%**	**Not visualized**	Total
Fluid overload	5(10%)	18(37%)	26(53%)	45(92%)	2(4%)	2(4%)	0(0)	49
Hypovolaemic shock	25(81%)	5(16%)	1(3%)	1(3%)	5(16%)	25(81%)	0(0)	31
Septic shock	19(86%)	3(14%)	0(0)	0(0)	6(27%)	15(68%)	1(5%)	22
Cardiogenic shock	3(16%)	3(16%)	13(68%)	13(68%)	3(16%)	1(5%)	2(11%)	19
PE	2(33%)	3(50%)	1(17%)	6(100%)	0(0)	0(0)	0(0)	6
Other	1(17%)	4(67%)	1((17%)	4(67%)	1(17%)	0(0)	1(17%)	6
Totals	**55**	**36**	**42**	**69**	**17**	**43**	**4**	**133**

Table 10: Cardiac contractility and IVC-CI (CCF congestive cardiac failure, PE pulmonary embolism, CNS central nervous system)

Ultrasound findings	Fluid overload (n=49)	Fluid depleted patients (n=53)
Poor contractility OR IVC-CI <25%	47(95%)	2(4%)
Hyperdynamic contractility OR IVC-CI>50%	6(13%)	51(96%)

Table 11: Combination of cardiac contractility or IVC-CI in fluid overloaded and fluid depleted (septic shock and hypovolaemic shock) patients.

5.4 Pericardial effusions

Fifteen patients had pericardial effusions confirmed on ultrasound. (Figure 19) Four of these patients had cardiac tamponade with effusions measuring more than 2 cm and right ventricular collapse. In all 4 these cases the diagnosis was definitive and immediate pericardiocentesis could be performed under USS guidance.

Of the other 11 patients in this group, 2 in were in hypovolaemic shock, 8 in CCF and one in cardiogenic shock. Two of the remaining 11 patients with effusions had effusions larger than 2cm, but did not have any other findings of cardiac tamponade.

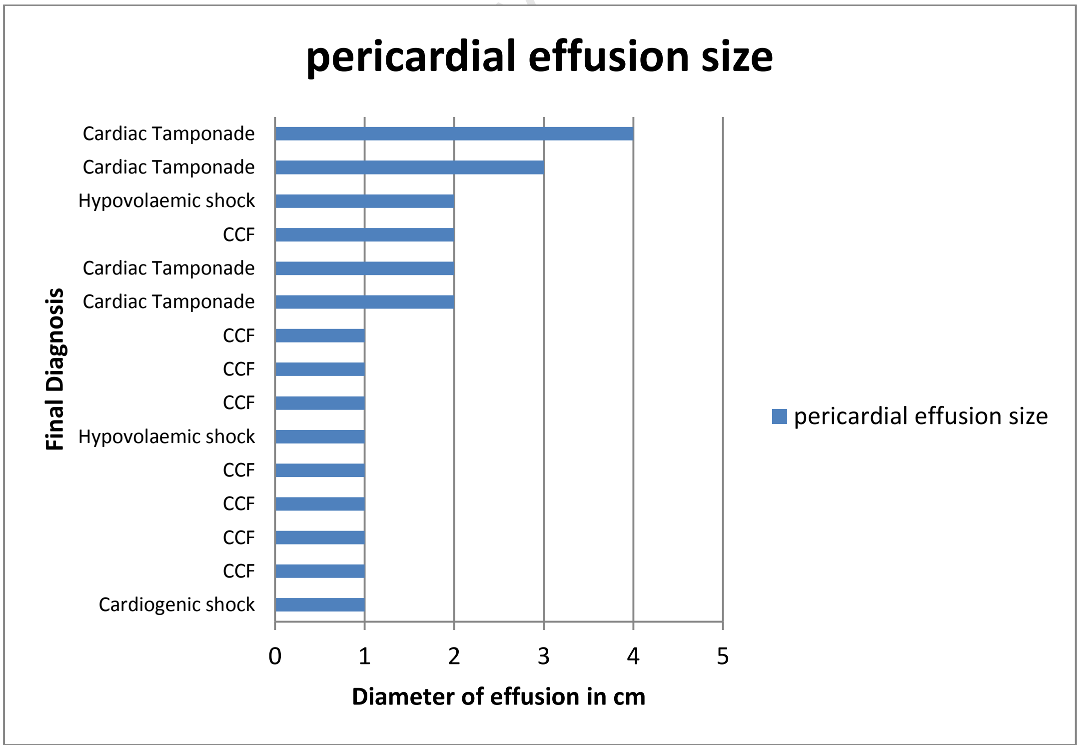


Figure 19: Pericardial effusions measured in cm and final diagnosis

5.5 FAST views

Forty five (34%) patients had positive FAST views. (Figure 20) Almost half the patients (n=25) diagnosed with fluid overload had free fluid either in the abdomen or in the chest. In patients with fluid overload, a positive FAST scan added to the other ultrasound findings can make the diagnosis more accurate.

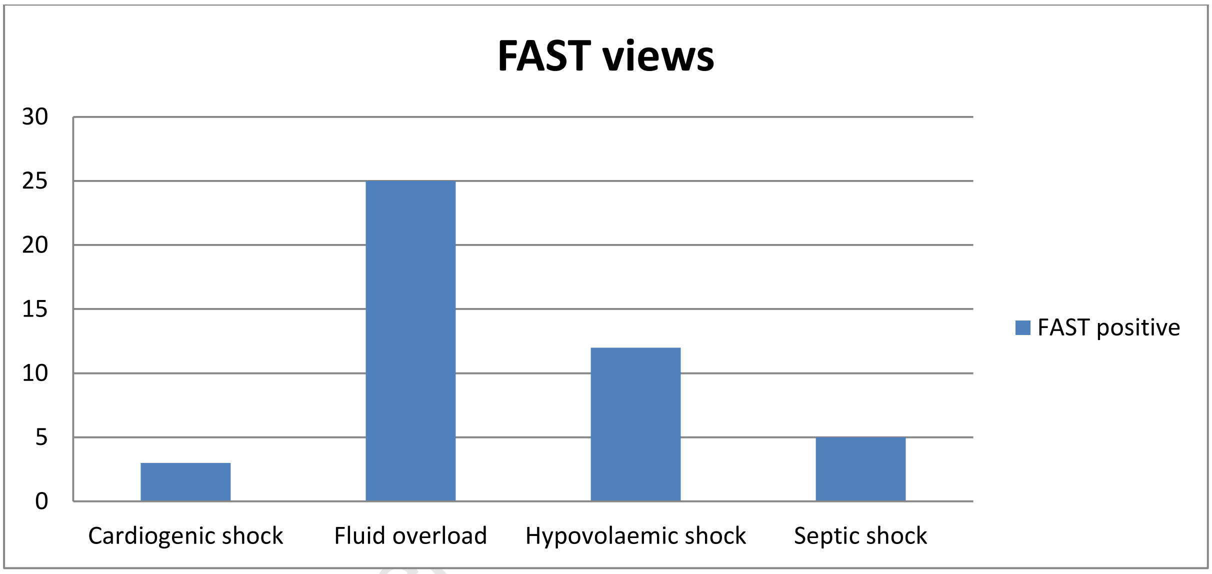


Figure 20: FAST views and diagnosis

5. 6 Abdominal Aorta Aneurism (AAA)

All patients did not receive an AAA scan. In 40% (n=53) the aorta was not visualized. Sixty percent (n=80) of the patients did have an AAA scan and the widest diameter was documented. AAA was detected in two cases with a diameter of more than 3 cm. These patients were diagnosed with septic shock and cardiogenic shock and had aortic diameters of 5.3cm and 3.11 cm measured half way between the xiphisternum and the umbilicus respectively. In all three cases the findings were coincidental and none of the patients had symptoms or CT evidence of a leaking AAA.

5.7 Pneumothorax

All patients included in the study were checked for pneumothorax. Only one patient was found to have a right sided pneumothorax .This patient was diagnosed with hypovolaemic shock and had a spontaneous pneumothorax due to a chronic chest infection. A successful thoracostomy was performed.

5.8 Time

For 89% of cases (n=118) time to USS were recorded. Seventy six percent (n=101) of patients were scanned within one hour of admission to the ED. (Table 12) Scans were delayed in the other 17 cases due to absence of the investigators during admission to the ED. Only 6% (n=7) of cases were scanned longer than 3 hours after admission.

Time to scan	**Number**
<10 mins	29(25%)
10 - 20 mins	23(19%)
20 - 30 mins	25(21%)
30 - 40 mins	8(7%)
40 -50 mins	5(4%)
50 - 60 mins	11(9%)
1 - 2 hours	5(4%)
2 - 3 hours	5(4%)
> 3 hours	7(6%)
Not recorded	15(13%)
Total	**133**

Table 12: Time between admission and scan

5.9 Final outcome

One hundred and twenty six (94%) patients improved after treatment was initiated and were stable enough to be discharged from the unit into the general medical ward. No patients were followed up on the general ward. Seven patients (5%) died in the unit. Three were diagnosed with catastrophic haemorrhagic stroke and had no haemodynamic abnormality. The fourth had a pulmonary embolism and mitral valve incompetence confirmed by formal echocardiogram. This patient arrested after chemical thrombolysis with tenectiplase. The fifth patient had cardiogenic shock and acute myocardial infarction and did not respond to treatment. The sixth patient had gastro enteritis and irreversible hypovolaemic shock and did not respond to fluid resuscitation or inotropes. The last patient had septic shock with bilateral lobar pneumonia and died due to respiratory failure.

6 Discussion

6.1 The Study Population

Over a period of 1 year a total number of 133 patients were included into the study. This study was purely performed in the emergency centre setting with undifferentiated critically ill patients. The study population has a normal distribution as demonstrated by the Shapiro-Wilk test. The closer this value is to 1, the more likely it is that the population is normally distributed. Furthermore, if the alpha value in this study is selected to be 0.001, the p-value of the Shapiro-Wilk test is 0.009. This means that the null hypothesis, that the population is normally distributed, cannot be rejected.

The skewness of 0.27 can be demonstrated visually by a normality or quantile-quantile plot (Q-Q plot) (Fig 21). The closer the plotted dots are to the normality line, the closer the population is to a normal distribution.

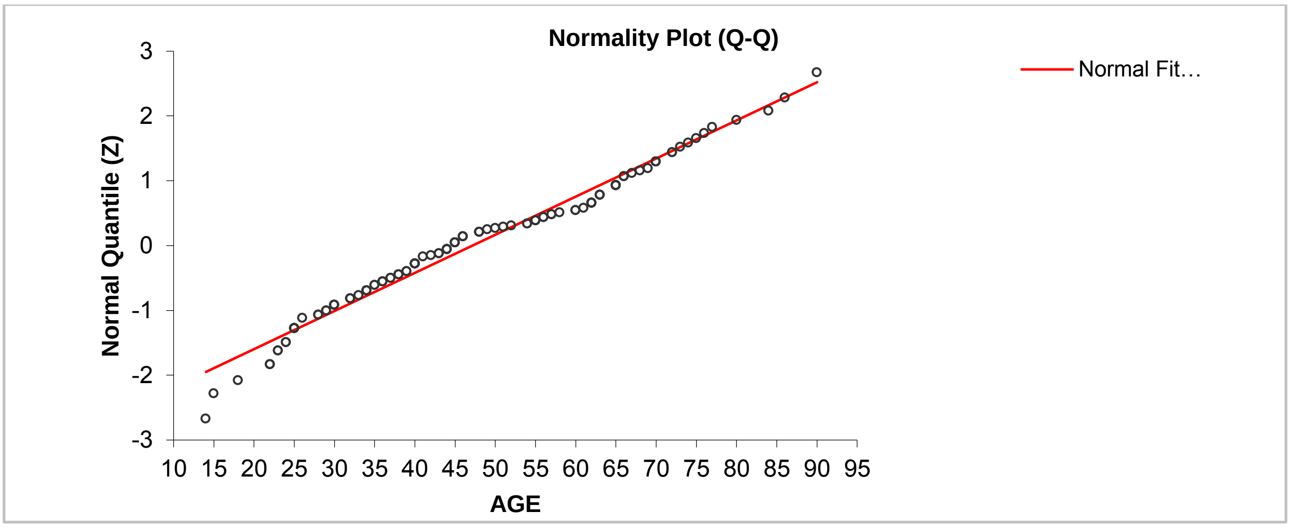


Figure 21: Q-Q plot to demonstrate normal distribution of the study population. The closer the plotted dots are to the normality line, the more likely it is that the population has a normal distribution

Numerous studies have examined the use of EUS cardiac echo or IVC-CI. Very few studies were done to investigate a combination of the two findings. The benchmark study that tested the HI-MAP scan protocol was Jones et.al. [27] in 2004, almost 6 years before the RUSH protocol was published under that title.

The study population was slightly bigger at 184 patients. Like in our study, they were emergency centre patients that were deemed haemodynamically unstable by the presence of at least one sign of poor perfusion such as low blood pressure or altered mental status. They were assessed by an EP and then randomized to either be scanned immediately or in 15 and 30 minutes after arrival. Patients also ranged from 17 years of age and upward.

We included people from the age of 12 years and above. The cut off age is lower because local policy determines that all patients 12 years old and below are paediatric patients and over the age of 12 are adults. In our study ventilated patients were excluded to remove the bias of possible effect of ventilation on ultrasound findings such as the IVC-CI. Trauma patients and patients in cardiac arrest were excluded as a different type of scan would be more appropriate such as FAST or FEER.

Our inclusion criteria were based on the South African triage score[82]. (Appendix 3) In order to quantify haemodynamic instability and include both groups of patients, those that are dehydrated and in shock, and those that are fluid overloaded and in cardiac failure, we had to look at both ends of the spectrum. When looking at the hypovolaemic group, we had to look at low blood pressure, tachycardia and increased respiratory rate. In the fluid overload or CCF group we had to look at high blood pressure, tachy- or bradycardia and also tachypnoea.

Of the 133 patients included in our study, 88% were included based on 2 of these criteria and the rest only based on one. (22%) The common denominator was that all the patients were deemed unstable by the attending EP during the ultrasound examination. When looking at the pooled vitals of the patients, the mean pulse rate was 120, which indicates that most patients were tachycardic. Blood pressure was the most unreliable vital with mean systolic blood pressure of 117 and diastolic of 70 mmHg. This falls well within the normal ranges of blood pressure. Respiratory rate was also a good indicator of distress with a mean of 44 breaths per minute. Unfortunately this vital was not documented in all cases.

6.2 Diagnosis

Jones et.al.[27] listed potential diagnosis in their randomized controlled trial. (Table 13) The problem with this list was that it did not include all diagnosis that one can find in the EC. The second problem is that trying to establish this list of diagnosis with specific ultrasound findings could be difficult and may not fall within the capabilities of the EP using ultrasound. Furthermore it is important to keep in mind that the HI-MAP scan is focussed and designed only to answer very specific questions. (Appendix 1) When looking at the list of diagnosis in table 13, the EP had to pick the most likely cause of hypotension from the list of 21 potential diagnoses. The aim was to compare the choices before and after EUS and determine whether the use of EUS makes early diagnosis more accurate. In our study this could not be done because it was retrospective. This created the problem that we could have any diagnosis listed in the ICD 10, making it impractical to use in this study. This was the rationale for categorizing diagnosis in our study. (Table 6 in section 4) This way we could compare provisional diagnosis with final diagnosis and look at the contribution or changes that the HI-MAP scan made to the original diagnosis or confirmation thereof.

Left ventricular failure	Tension pneumothorax
Hemoperitonium	Anaphylaxis
Severe dehydration	Neurogenic shock
Cardiac tamponade	Valvular dysfunction
Pulmonary embolus	Occult medication error or overdose
Sepsis	Ruptured aneurism
Aortic dissection	Myocardial ischemia or infarction
Thyrotoxicosis	Adrenal failure
Dysrhythmia	Autonomic dysfunction
Occult gastro intestinal bleed	Mesenteric ischaemia
Abdominal inflammation	

Table 13: Potential diagnosis listed in Jones et.al.[27]

In our study we kept provisional and final diagnosis the same accept for undifferentiated patients. Undifferentiated was only used for the provisional diagnosis because without further investigation or ultrasound, the diagnosis could not be made. Twenty one patients were documented as undifferentiated. All 21 of these patients could be fitted into a diagnostic category after the HI-MAP scan was performed. This demonstrates the value of EUS in early diagnosis of the undifferentiated critically ill patients. In all these patients the scan was performed within the first hour after admission. This would fit in with the conclusion made by Jones et.al. , that the use of focussed ultrasound by trained physicians could lead to more accurate and faster diagnosis.

When comparing the final diagnosis after ultrasound to the findings in Jones et.al. it is clear that they used a similar categorization. (Table 14) Even though there were many sub diagnosis, the basic categories was still similar to our study and included Infectious/distributive, cardiovascular, toxicology and other. It is not possible to distinguish the difference between distributive and infectious shock by using focussed EUS only. We categorized this group of shocked patients as hypovolaemic shock and septic shock. Cardiovascular was categorized as cardiogenic shock and congestive cardiac failure (CCF) which was further categorized as fluid overload. PE was also left separate as it is a very specific ultrasound diagnosis as described earlier.

Final diagnosis	Percentage	Final diagnosis	Percentage
Infectious/distributive	77	Cardiovascular	15
• Septic shock	43	• Cardiomyopathy	9
• Severe dehydration	28	• Acute myocardial infarction	2
• Occult gastro intestinal bleeding	3	• Dysrhythmia	2
• Hemoperitonium	2	• PE	1
• Adrenal insufficiency	1	• Ruptured Aortic aneurism	1
Toxicology	7	Other	1
• B blocker toxicity	3	• Anaphylaxis	<1
• Ca channel blocker toxicity	2	• Heat stroke	<1
• Polypharmacy	2	• Mesenteric ischaemia	<1

Table 14: Final diagnosis from Jones et. al.[27]

Looking at provisional diagnosis, 39% was fluid overload, 14% hypovolaemic shock and 16% septic shock. Compared to Jones et.al., we had a much higher occurrence of fluid overload. As mentioned before, CCF and other reasons for fluid overload such as renal failure were included in this diagnosis. This is due to the inclusion criteria that were set in such a way that not only patients in shock or hypotension were included, but also patients in distress due to cardiac failure as recognized by high blood pressure, pulmonary oedema and respiratory distress. In Jones et.al. patients were only included if they were in hypotension.

In our study 87 patients had a similar diagnosis after EUS was completed. This was 65% of patients. In Jones et.al only 2 out of the 184 patients had a completely different diagnosis from the initial diagnosis. There were two reasons for this. In the first place, they had to select a differential diagnosis on a data sheet after initial assessment. The final diagnosis after ultrasound was then compared to the differential and if marked, was taken as the same. The second reason was that not all possible differentials were listed on their data sheet. In comparison, our study defined all patients with uncertain diagnosis, or more than one differential, as undifferentiated. After ultrasound, all patients could be allocated to a proper final diagnosis.

In the other third of patients, ultrasound changed the diagnosis completely. This included the undifferentiated cases which could be seen as uncertain diagnosis. In 23% of patients initially thought to be fluid overloaded, the diagnosis turned out to be either hypovolaemia or septic shock, which means that treatment without ultrasound or further investigation could have been deleterious to these patients. Patients that were already dehydrated could have been fluid restricted or given diuretics. 33% of patients diagnosed with sepsis initially, turned out to have a different cause for haemodynamic instability. Two cases were labelled as hypovolaemic shock which is not easily distinguishable from septic shock. (Hyperdynamic contractility with IVC-CI >25%) One case was normovolaemic and two had severe CCF. In the latter cases, initiating treatment for hypovolaemia would have been catastrophic for the patients, as they were already overloaded.

In Khouli et.al[31], a similar study, comparing right heart catheterization, trans-thoracic echo (TTE) and the gold standard of expert clinician assessment with all data in 51 patients, a correlation of diagnosis was reached in 90% of cases. Initial clinical assessment of patients with cardiopulmonary compromise was wrong in 73% of the patients before ultrasound changed the diagnosis. When compared to our study, this number is larger. Their TTE was much more detailed and complicated than the HI-MAP scan and included flow rate determination and end diastolic ventricular volume measurements. They included PAC measurements in their gold standard assessment that could have led to more accurate diagnosis than in our study. The aim of their study was to determine whether ultrasound would lead to better total assessment of critically ill patients and initiation of treatment and similar to our study, was successful in proving that.

The conclusion in this study was that the utilization TTE in diagnostics of critically ill patients in the ICU with cardiopulmonary compromise is safe to use, accurate in identifying the aetiology and providing treatment recommendations.

6.3 Cardiac contractility and IVC collapsibility

The combination of IVC-CI and cardiac contractility are the most overwhelming clinical findings in our study. In patients with CCF and fluid overload, IVC-CI is less than 25% in 92% of patients. This was the largest proportion of patients in our study. When compared to Jones et.al., they did not include patients with pure cardiac failure or fluid overload, but only hypotensive or shocked patients. IVC-CI was only measured if they noted some collapse during respiration. The largest proportion of their patients was diagnosed with infectious or distributive shock and had ultrasound findings different to ours. IVC collapse of more than 50% was found in 53% of these patients compared to 68%-81% in our results. Cardiac contractility was unfortunately not mentioned for their septic patients. Our results pointed out that hyperdynamic cardiac contractility is the most common ultrasound finding in septic and hypovolaemic patients with 81%-86%.

In patients with cardiogenic shock we found that 68% had poor contractility as well as IVC-CI of less than 25%. This correlates exactly with Jones et.al besides that they did not look at IVC collapsibility of less than 25%, but measured IVC collapsibility of more than 50% in 12% of patients vs. 5% in our study. It is unclear what the reasons were for this finding in Jones et.al.

We suggest a combination of cardiac contractility and IVC-CI with EUS to determine the hydration status of a critically ill patient. We demonstrated that if either poor contractility or IVC-CI of less than 25% is present, the chances are good that the patient is in CCF or fluid overload. IVC-CI is more specific for this condition. To determine the exact sensitivity and specificity, a need for further research exists. The most challenging obstacle with this research is finding an accurate, objective and repeatable "gold standard" to compare the findings to. Proper outcomes must be measured and a no-ultrasound group of patients must be used as a control. It is however questionable whether it is ethically acceptable to withhold ultrasound diagnosis from a critical patient when its use is already so integrated into emergency medicine and critical care.

6.4 Pericardial effusions

The presence of pericardial effusions was detected in 15 patients. Four had cardiac tamponade. Because the sensitivity and specificity of the EP detecting pericardial effusions is so high, it makes sense to include this step in the HI-MAP scan. Out of 133 critically ill patients, four were diagnosed with cardiac tamponade and treatment could immediately be initiated. Even though the findings were few, the detection of tamponade was life-saving in all these cases.

In the other 11 cases, the detection of pericardial effusion could indicate other disease processes such as extra pulmonary tuberculosis (TB). A study done in South Africa in 2010, showed a 52% incidence of pericardial effusion in patients with extra-pulmonary TB.[85] This could make the diagnosis of sepsis more likely due to immunosuppression and opportunistic infections.

6.5 FAST views

In CCF and fluid overload, common clinical findings are pitting oedema, hepatomegaly and ascites. Ascites is usually a late sign in the process of CCF. In almost half the patients with a positive FAST scan in this study, had a final diagnosis of CCF. The detection of free fluid in the peritoneal cavity does not give an accurate estimate of hydration status of a patient. In combination with clinical findings, cardiac contractility and IVC-CI, the FAST scan will add to the diagnosis of CCF or fluid overload. A positive FAST scan is of limited value in making a diagnosis of sepsis and hypovolaemic shock in a patient unless an intraperitonial haemorrhage or perforation is suspected. The FAST scan does not seem to be the optimal addition to the HI-MAP scan. The inclusion of a more detailed abdominal ultrasound examination might improve the diagnostic value of the HI-MAP scan. A specific stepwise evaluation has been described and includes evaluation of the liver, biliary tract, pancreas, kidneys, spleen and aorta.[86] This evaluation is aimed at assessment of the stable patient with an acute abdomen. The complete evaluation will take longer than the FAST views as it is a more detailed examination with particular measurements that need to be documented for each part of the scan. Aorta and the kidneys are already viewed when performing the HI-MAP scan. Including a few more binary questions to focus the examination could add extra value diagnosing the critically ill patient and also keep the evaluation time as quick as possible.

Specific scans have been developed for TB abdomen (FASH)[84] and acute abdomen.[85] None of these scans have been tested in the emergency setting, thus creating the need for further research. Almost all these scans are rated as level 2 EUS scans, and would probably benefit the more experienced EP.

6.6 Abdominal aorta aneurism

Even though the AAA scan was performed in 60% of patients, aortic widening was only detected in three patients. On none of these patients AAA was the cause of the haemodynamic instability. This did however identify pathology that could be thoroughly investigated once the patient was stabilized. When determining the cause of haemodynamic instability in this study, the AAA scan was of limited value. When indicated by the signs and symptoms of a leaking AAA, the scan is accurate in diagnosing AAA with specificity and sensitivity of close to 100%[72] when performed by the EP. The AAA scan is sometimes difficult to perform due to the presence of bowel gas or a high body mass index.

6.7 Pneumothorax

Pneumothorax was only identified in one patient, and was not the cause for the patient's shock. All the patients in the study had this view done. This scan is easy to perform and very sensitive for detecting a pneumothorax. A tension pneumothorax will cause severe shock and distress, but should be a clinical diagnosis followed by rapid needle decompression and intercostal drain insertion. If this is not diagnosed clinically, ultrasound could delay the treatment and lead to cardiac arrest. A large pneumothorax may cause respiratory distress and could be detected by ultrasound if not found clinically or could be confirmed if bedside x-ray is not available. Overall the value of the pneumothorax scan in the HI-MAP protocol is limited, but can be helpful when indicated.

6.8 Time

Part of the objectives of this study was to indicate the use of ultrasound saves time when diagnosing critically ill patients. Time to scan was recorded in 89% of cases. This was the time between admission to the unit and performing the scan. Most patients were scanned in under an hour. A quarter of the patients were scanned in under 10 minutes of arrival to the unit. This indicates that almost 90% of patients in the study were diagnosed in under an hour and treatment initiated. Even though the patients were not compared to a control group, it is unlikely that special investigations would have been done within the same time frame.

In future studies time to scan should be a primary endpoint and should be compared to a standard of care control group with no EUS performed. One of the strongest advantages of EUS is that it can be done at the bedside and due to its focussed nature, could be done in a short time. Future studies should also determine the duration of the HI-MAP scan when performed by different doctors.

6.9 Weaknesses

This study was a retrospective descriptive study of the departmental ultrasound database. The HI-MAP scan was performed in the EC at Ngwelezane Hospital for almost a year before the starting date of this study. Even though the HI-MAP protocol was very specific, documentation of the findings was made prior to planning this study. This explains why certain data such as GCS and respiratory rate were not recorded in all cases. Consequently it was also not possible to follow up patients after discharge from the unit, as this would be time consuming, labour intensive and due to a non-computerized archive system, not practical to do.

The HI-MAP scans could only be performed when one of the two level 1 EUS qualified doctors was on site. This contributed to a relatively small study population. In future HI-MAP studies, more investigators would reduce the possibility for bias. It could demonstrate that the HI-MAP scan is reproducible and equally accurate in less experienced hands.

The HI-MAP scan and final diagnosis were performed and determined by the same doctor in every individual case. Only the provisional diagnosis was made by the attending medical officer. In some cases the investigators did the complete patient work-up without a second opinion. Even though there was potential for bias in documentation of ultrasound findings and final diagnosis, the data was only collected to supplement the departmental audit and not to answer specific questions.

Another weakness was that there was no "gold standard" investigation to compare the ultrasound findings with. In Jones et al the gold standard was taken as expert evaluation of patient through clinical examination and assessment of all special tests and invasive fluid monitoring[27]. We used the same method to determine final diagnosis without any blinding, and were therefore unable to objectively assess the accuracy of the final diagnosis. Both investigators have extensive experience in emergency medicine and have adequate diagnostic skills.

This study was performed in a single EC. The study population was representative of the general population, which are mostly Zulu people. Unfortunately the race and body mass index of patients were not recorded which could be responsible for confounded bias. This raises the question whether the HI-MAP scan would be as effective in other population groups.

The inclusion criteria provided that children of twelve and over were included in the study even though most international studies excluded children under the age of 14 years. This inclusion criterion was set because it is part of the general case load of the unit. However, the youngest patient was 14 years old. There was only one person under the age of 14. For future studies paediatric cases should be excluded.

7 Recommendations

Emergency ultrasound performed by the EP has developed over the past three decades and is on the syllabus of most emergency medicine training programs across the globe. Various different applications have been identified in the emergency centre including diagnostics, procedures and focussed examinations. Due to technological advancement, the ultrasound machines have been y institution improved by becoming smaller and producing higher quality images. More calculations can be done and images can be stored digitally or even sent over long distances via the internet to be assessed by experts. The cost has also reduced and thus made machines available to almost every EC in developed and even developing countries. It is relatively easy to learn and quick to perform. It is non-invasive and does not subject patients to radio activity. In order to keep developing EUS, more doctors should be trained to use this modality on a day to day basis.

Further research is needed in the evaluation of hydration status in patients with the use of EUS. Studies to determine the sensitivity and specificity of the HI-MAP scan need to be undertaken, after an acceptable “gold standard” has been identified. At present the use of PAC, APWA and CVP catheters in combination with expert clinician has been used. Multi centre cohort studies should be done both nationally and internationally to make the application of HI-MAP more appropriate and universally accepted.

Accuracy and reproducibility of the HI-MAP scan by both senior and junior clinicians should be investigated and reported.

8 Conclusion

The HI-MAP scan is a level one emergency ultrasound scan. It can be performed at the bedside of critically ill patients and can be performed by doctors with basic emergency ultrasound training. Most scans can be performed immediately during initial assessment of a patient. It is designed to answer specific questions in order to lead to an accurate diagnosis of the critically ill patient in the emergency centre.

In this study the use of this scan led to a finding a different diagnosis from the provisional diagnosis in more than 35% of cases. The adjunct of the HI-MAP scan to the clinical examination and history of the patient therefore improves the accuracy of diagnosis and could lead to more appropriate treatment earlier. Whether it will change the final outcome in terms of mortality or length of hospital stay remains to be investigated. In this study the most helpful aspects of the scan were cardiac contractility and IVC-CI.

Cardiac contractility was hyperdynamic in most of the patients with septic or hypovolaemic shock and IVC-CI was above 50%. In patients with fluid overload, the most sensitive sign was IVC-CI of less than 25% in more than 92% of patients. Cardiac contractility was only poor in half those patients and normal in the remainder, which means that as a standalone parameter, it is not very good to indicate fluid overload.

The combination of these two parts of the HI-MAP scan showed the most promising results in predicting the presence of fluid overload or hypovolaemic/septic shock. The rest of the scan can add to the value by very specific findings such as AAA, or the presence of a pneumothorax. The FAST views could strengthen the diagnosis of fluid overload, but may also indicate the source of sepsis as intraperitonial.

Finally, it is important to note that the HI-MAP scan should be used as an adjunct to the clinical assessment of the patient and not as a standalone investigation.

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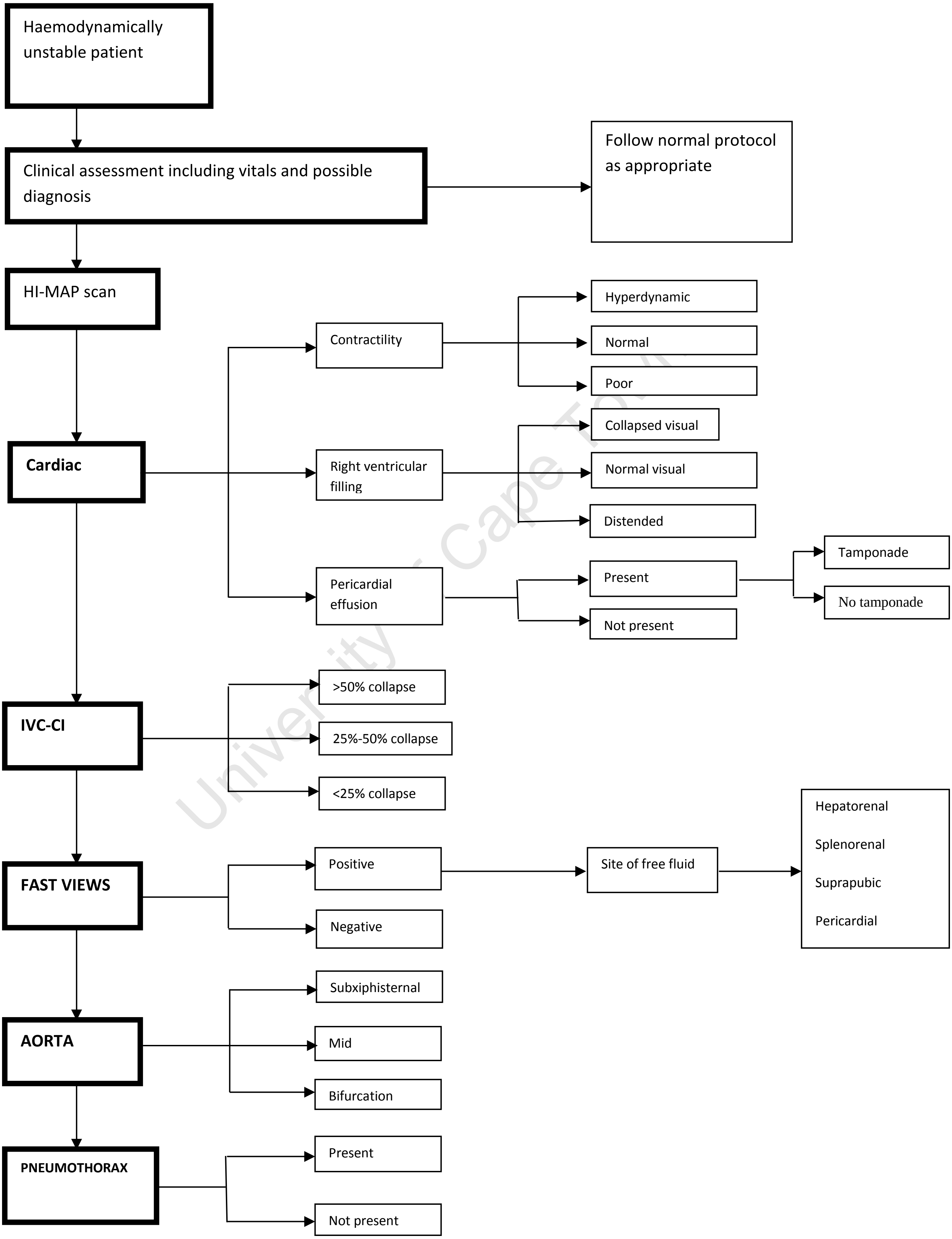
10 Appendixes

Appendix 1: HI-MAP SCAN PROTOCOL



Appendix 2: HI-MAP data collection sheet

Number:

Initials: Time of admission:

Age:

Date: Time scanned:

Pulse: Time of diagnosis:

BP: Male ☐ Female ☐

Findings on examination:

Provisional diagnosis:

Findings: **Cardiac**

Contractility Poor ☐/ normal ☐/ Hyper dynamic ☐ **Effusion** Yes ☐/No ☐
RV filling Good ☐ /poor ☐ **LV:RV** >1☐ /<1☐

IVC

Diameter cm: **Collapse** >50%☐ /25%-50%☐ /<25%☐/ no collapse☐

FAST Views

Negative: ☐ **Positive:** ☐ **Site:**

Aorta

Diameter: **Prox:** **Mid:** **Inf:**

Pneumothorax

Yes ☐ No ☐

Final diagnosis:

Outcome:

Improved: Yes☐/No ☐ **Diagnosis accurate:** Yes☐/No☐ **Confirmed:** Yes☐/No☐
Method:

USS:

ADULT TRIAGE SCORE								© South African Triage Group 2008
	3	2	1	0	1	2	3	
Mobility				Walking	With Help	Stretcher/ Immobile		Mobility
RR		less than 9		9-14	15-20	21-29	more than 29	RR
HR		less than 41	41-50	51-100	101-110	111-129	more than 129	HR
SBP	less than 71	71–80	81-100	101-199		more than 199		SBP
Temp		Cold OR Under 35		35-38.4		Hot OR Over 38.4		Temp
AVPU		Confused		Alert	Reacts to Voice	Reacts to Pain	Unresponsive	AVPU
Trauma				No	Yes			Trauma
over 12 years / taller than 150cm								

Colour	RED	ORANGE	YELLOW	GREEN	BLUE
TEWS	7 or more	5-6	3-4	0-2	DEAD
Target time to treat	Immediate	less than 10 mins	less than 60 mins	less than 240 mins	
Mechanism of injury		High energy transfer			
Presentation		Shortness of breath - acute		ALL OTHER PATIENTS	DEAD
		Coughing blood			
		Chest pain			
		Haemorrhage - uncontrolled	Haemorrhage - controlled		
	Seizure - current	Seizure - post ictal			
		Focal neurology - acute			
		Level of consciousness reduced			
		Psychosis / Aggression			
		Threatened limb			
		Dislocation - other joint	Dislocation - finger or toe		
		Fracture - compound	Fracture - closed		
	Burn – face / inhalation	Burn over 20%	Burn - other		
		Burn - electrical			
		Burn - circumferential			
		Burn - chemical			
		Poisoning / Overdose	Abdominal pain		
	Hypoglycaemia - glucose less than 3	Diabetic - glucose over 11 & ketonuria	Diabetic - glucose over 17 (no ketonuria)		
		Vomiting - fresh blood	Vomiting - persistent		
		Pregnancy & abdominal trauma or pain	Pregnancy & trauma		

Appendix 3: South African triage score