COMPARISON OF BLOOD PRESSURE IN THE ARM AND ANKLE IN PATIENTS IN THE EMERGENCY DEPARTMENT

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A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, in partial fulfilment of the requirements for the degree

of

Master of Medicine in Emergency Medicine.

Johannesburg, 2012

DECLARATION

I, Lara Nicole Goldstein, declare that this research report is my own work. It is being submitted for the degree of Master of Medicine (Emergency Medicine) at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.

DEDICATION

This work is dedicated to my mom, Lindy, my dad, Michael, my brother, Ashley and my moiety, Mike.

ABSTRACT

Objectives:

1. To establish whether the differences between the arm and ankle non-invasive blood pressure (NIBP) measurements of Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP) and Mean Arterial Pressure (MAP) are clinically relevant (i.e. a difference of ≥ 10 mmHg).

2. To determine whether any patient characteristics (age, sex, race, height, weight, body mass index (BMI), arm circumference, ankle circumference, presenting complaint, and tobacco usage) influence the difference between ankle and arm NIBP measurements.

Design:

Prospective cross-sectional study

Setting:

Netcare Union Hospital Emergency Department (ED)

Patients:

All patients from 18 to 50 years of age presenting to the ED who were not in need of emergency medical treatment and who consented to participating in the study.

Methods:

Patients had their blood pressure measured whilst lying in the supine position. The blood pressure was measured on both arms and ankles with the correct size cuff according to manufacturer's guidelines. All appropriate data was recorded.

Main Results:

The blood pressure measurements in the arm and ankle were compared. SBP measurement in the ankle was found to be inaccurate when compared to the arm and thus cannot be used as a substitute for arm SBP. Ankle DBP is the most accurate and deviates from the actual arm DBP within the clinically acceptable range of 10 mmHg. MAP difference is clinically acceptable on average, but the 95% CI show that the range extends beyond the clinically acceptable range.

Conclusions:

Ankle blood pressure should not be used as a substitute for arm blood pressure in the Emergency Department.

ACKNOWLEDGEMENTS

I am grateful for the time and assistance given by the following people:

- My supervisor, Dr M. Wells.
- My co-supervisor, Prof. K. Sliwa.
- Statistician – Dr M. Wells for his patience in this regard.
- Nursing and administrative staff at Netcare Union Hospital Emergency Department.
- Johan Roodt and the Medhold/GE Healthcare team for the loan of the Carescape V100 Vital Signs Monitor.

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NOMENCLATURE

Abbreviations

AAMI	Association for the Advancement of Medical Instrumentation
AHA	American Heart Association
ABI / ABPI	Ankle-Brachial Index / Ankle-Brachial Pressure Index
BHS	British Hypertension Society
BMI	Body Mass Index
BP	Blood Pressure
BPM	Beats Per Minute
CI	Confidence Interval
CIRC	Circumference
cm	Centimetre
CURB65	See definitions below
DBP	Diastolic Blood Pressure
DINAMAP™	Device for Indirect Non-invasive Automatic Mean Arterial Pressure
ED	Emergency Department
ESH	European Society of Hypertension
HOB	Head Of Bed
JNC	Joint National Committee
kg	Kilogram
m	Metre
MAP	Mean Arterial Pressure

mmHg	Millimetres of mercury
mmol/L	Millimoles per litre
NIBP `	Non-Invasive Blood Pressure
NS	Not Significant
PP	Pulse Pressure
SBP	Systolic Blood Pressure
SD	Standard Deviation
yo	Years Old

Definitions

ABI

The ankle-brachial index is the systolic blood pressure measured at the ankle divided by the systolic blood pressure measured in the arm during supine rest [1].

ANKLE

“The narrowest and malleolar part of the distal leg, proximal to the dorsum and heel of the foot, including the ankle joint” [2].

ARM

The anatomical area which extends from the shoulder to elbow.

AVERAGE

The term average will be used in the statistical analysis to denote the mathematical mean. This is in order to avoid confusion that may occur because of the use of MEAN arterial pressure (MAP).

BMI

This is the Body Mass Index. It is calculated by:-

$$BMI = \frac{Weight\ (kg)}{Height^2\ (m^2)}$$

CALF

This is the posterior prominence of the leg caused by the *triceps surae muscle*[1] from which the Achilles tendon extends to reach the heel [2].

CURB65 [3]

Score used to predict mortality in patients with community-acquired pneumonia. Criteria include:-

- **C**onfusion
- **U**rea > 7 mmol/L
- **R**espiratory rate > 30 breaths per minute
- **B**lood pressure SBP < 90 mmHg or DBP < 60 mmHg
- **A**ge ≥ 65 yo

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[1] This includes the medial and lateral heads of the gastrocnemius muscle and the soleus muscle

FOREARM

The anatomical area which extends from the elbow to the wrist.

LEG

The anatomical area which extends from the knee to the level of the medial and lateral malleoli [2].

LIMITS OF AGREEMENT

The agreement between the blood pressure readings in the arm as the gold standard compared to another site using the Bland-Altman approach [4]. These are the 95% confidence intervals (CI).

$$CI = Average\ difference\ \pm\ (SD\ \times\ 1.96)$$

P VALUES

A P-value of < 0.05 will be considered statistically significant. Very small P-values will be reflected as “P < 0.0001” and exact figures will be used for larger values.

THIGH

“The anatomical area of the free lower limb which lies between the gluteal, abdominal and perineal regions proximally and the knee region distally” [2].

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PREFACE

The clinical significance of a difference in blood pressure between the arm and the ankle never struck me until as a junior registrar I was instructed by a senior registrar in anaesthesia to place the BP cuff on the ankle of a post-operative caesarean section patient to satisfy the nursing staff in recovery that her BP after the spinal anaesthetic was not in fact as low as they had measured it (in the arm). It got me pondering as to how many decisions I had made in the past that were potentially incorrect based on a blood pressure when I didn't note where the cuff was placed, what the patient's body habitus was like, how the blood pressure was obtained and what was the position of the patient.

With this study, I wanted to find out whether there was a consistent link between the BP measured in the arm and the ankle and which therefore could mean that the ankle BP could be reliably used in patients.

I wanted to look for the "missing link"…

Chapter 1 INTRODUCTION

Motivation and rationale for this research

Blood pressure (BP) is one of the most important vital signs required in the Emergency Department (ED) and is essential to guide the resuscitation of the critically ill or injured patient. Ideally, blood pressure should be measured directly or invasively when precise or continuous monitoring is required but this can be time consuming and impractical to institute in a resuscitation setting. Non-invasive blood pressure (NIBP) measurement is most often used in the ED for triage, initial patient assessment and on-going management of the stable patient as well as the unstable hypotensive or hypertensive patient. NIBP is a truly “vital” sign in the ED from a diagnostic, prognostic and therapeutic perspective. The utility of NIBP measurement, along with other clinical signs, would include the detection of an abnormally high or low blood pressure in symptomatic or asymptomatic patients.

With the decreased availability of mercury sphygmomanometers (as a result of health hazard banning in some countries and environmental concerns with respect to mercury contamination) and the inaccuracy of aneroid manometers together with their need for regular calibration, there is increasing reliance on the use of automated oscillometric devices in the clinical setting. Oscillometric devices measure MAP directly but make use of calculations in order to derive systolic and diastolic blood pressure values and may be erroneous at the extremes of blood pressures [5]. Unfortunately there is a lack of awareness of the limitations of these automated devices.

The majority of guidelines regarding how the measurement of NIBP should be performed emphasise the importance of blood pressure determination from the point of view of identifying hypertension [6-8]. Although this is of relevance in the ED with respect to identifying hypertensive urgencies, hypertensive emergencies and hypertension as a risk factor for cardiovascular disease, acute hypotension is also of concern in the initial and subsequent evaluation of a severely ill or injured patient. NIBP is a pivotal component in the evaluation of patient stability in the triage setting as well as once the patient is in the ED.

In patients who are not severely ill or injured, it is reasonable to expect that blood pressure measurements will be performed on one of the patient's arms according to standard practice guidelines. This is not the case with the critically ill or injured patient who may not be able to be positioned correctly or where access to an arm may not be feasible. This sometimes requires healthcare providers to place the NIBP cuff on the ankle. Another problem is the fact that the same cuff size may not always be suitable for a particular patient: a standard adult cuff may be apt for both the arm and ankle in some patients, but this might not be applicable to all patients (e.g. the morbidly obese).

Blood pressure measurements may influence certain decisions regarding patient management in the ED (e.g. whether to give fluids or start inotropic support or initiate BP lowering therapy). If the decision not to start this vital treatment is based on a misleading reading, this would negatively affect patient outcome. There is no consensus in the literature regarding the interchangeable use of arm and ankle blood pressures in the Emergency Department nor in other clinical settings. As early as 1925, it was found that the systolic blood pressure was 20 to 40 mmHg higher in the leg than in the arm in normal subjects at rest [9]. The potential for interchangeability has been evaluated in anaesthetised patients with no consensus being reached. Pregnant patients had significant differences in their systolic and diastolic blood pressures but no differences in their mean arterial pressures in a study by Zahn *et al*. Although there was a tendency for the systolic BP to be higher in the arm and the diastolic pressure to be lower in the calf than in the arm, there was a large degree of variability amongst the patients [10]. Sanghera *et al*. found no association between arm and ankle blood pressures in pregnant patients during caesarean section [11]. Anaesthetised children also have inconsistent results with arm vs ankle blood pressure measurements – in children 8 years and younger, blood pressures were found to be lower in the leg than in the arm [12] whereas another study showed no link between arm and ankle blood pressure at all [13]. Wilkes and DiPalma advised that, although ankle systolic and mean arterial pressures were higher than in the arm in their cohort of anaesthetised patients, the ankle was an acceptable alternative should the brachial area not be available [14]. Conversely, Block and Schulte found that although the systolic blood pressure was higher in the ankle than in the arm, the mean blood pressures were statistically equivalent suggesting that ankle cuff placement is a reliable alternative to the arm [15]. This inconsistency in results does not allow for the extrapolation of this information to the ED nor does it condone the use of the ankle blood pressure measurements in management decisions for critically and injured patients during a resuscitation.

Blood pressure measurements are a fundamental part of patient management in the resuscitation setting in the ED. Whether there is a clinically significantly difference between arm and ankle blood pressures in the ED setting has not as yet been determined. Before assessing this in the hypo- or hypertensive seriously ill or injured patient, the equivalence or not must be shown in normal/mildly ill/injured patients. These measurements need to be performed in the supine position in order to simulate the resuscitation setting.

Requirements for blood pressure measurement in the ED

In the ED, the measurement of blood pressure is needed

- For triage purposes
- As an adjunct to identify shock
- For continual monitoring and evaluation of interventions

In general, 10% of patient presentations to the ED are for truly urgent conditions and 90% for non-urgent conditions. Although the vast majority of patients have non-urgent conditions, it is the 10% of critically ill or injured patients which brought about the need for Emergency Medicine. The 90% of non-critical patients also need expert initial evaluation in order for their reason for presenting to hospital as an emergency to be resolved. Irrespective of whether they are presenting to a large, tertiary, academic centre or a small, rural hospital, patients need to be categorised according to their acuity so as to ensure that the sickest are attended to first. This process needs to be quick, easy and accurate in order to prevent patient morbidity and mortality. One of the discriminators used to decide on the appropriate triage of these patients is blood pressure.

The use of BP measurement in the ED does not stop there. After the patient's initial classification, blood pressure can then be used for diagnosis and monitoring purposes. In the critically ill or injured patient, the trend of blood pressure can be used to evaluate the physiology of the circulation and assess whether current interventions to improve the patient's haemodynamic status are working or whether further interventions need to be instituted. Obtaining a BP reading in the resuscitation setting cannot be delayed, nor should it be complex or inaccurate.

Similarly, in the patient who is not acutely ill, BP can be used as a diagnostic tool. Hypertension affects approximately 1 billion people worldwide [16]. If left untreated, morbidity and mortality escalate. The higher the blood pressure, the higher the risk of myocardial infarction, heart failure, stroke and kidney disease [16]. The BP obtained in the ED can be used as a warning that the patient requires further follow-up and potentially needs treatment [17].

BP readings can also mean the difference between outpatient treatment and hospitalisation for a patient (e.g. the CURB65 score in pneumonia [3]).

Alternative options for BP measurement

The concept of blood pressure measurement has been in existence since the 18th century. Various modalities have been proposed in order to accurately measure it non-invasively, each with its own advantages and limitations. From cuff size to arm position to unit of measurement, the blood pressure measurement is full of loopholes and intricacies of which the end user is frequently unaware. The BP measurement that appears on the monitor is fraught with imprecision in itself yet commonly assumed to be the truth. The ease of use of an oscillometric device and the assumed precision of a digital readout may mask the underlying inexactness of the reading. Every time the measurement technique deviates from the standardised methods, the inaccuracies accumulate, compounding the potential for error. Different degrees of accuracy are required in different circumstances (e.g. the diagnosis of hypertension requires a different degree of accuracy than when allowing for permissive hypotension in a critically injured trauma patient). In using BP measurements, we need to attempt to strike a balance between precision and pragmatism. A simple manoeuvre derived from necessity, such as placing a blood pressure cuff on the ankle instead of the arm in a resuscitation setting may lead to a domino effect of errors, leading to patient mismanagement due to over-reliance on the need for a number.

Strategies for improving BP measurement in the ED

An awareness of the discrepancy between what we need and the limitations of what we have is one of the first solutions to this problem. A cognisance of how the readings can possibly be misleading is the key to accurate interpretation. Perhaps if certain factors were constantly taken into account or certain prerequisites fulfilled prior to measuring BP, a uniform link could be made between the BP that would have been obtained in the arm and that which was measured in the ankle thereby allowing the alternative site to be a feasible replacement in a time of necessity.

An understanding of the errors associated with BP measurement reinforces the truism: “Treat the patient and not the number”.

Statement of the problem

A quick and reliable alternative method to the classic arm blood pressure measurement reading is required in the ED when the BP cannot be measured in the arm. To date it has not been established whether ankle blood pressure can be substituted for traditional arm blood pressure measurement within a framework of clinically acceptable errors. This study evaluated the ankle as a valid alternative and whether there were any identifiable factors which affected its accuracy.

Aim and objectives

Study aim

The aim of this study was to establish whether there is a clinically relevant difference between ankle and arm NIBP measurements in an ED setting in non-critically ill or injured patients aged 18 to 50 years.

Study objectives

1. To define and compare the NIBP measurements obtained from the arm and the ankle.
2. To establish whether the differences between the arm and ankle NIBP measurements of SBP, DBP and MAP are clinically relevant (i.e. a difference of ≥ 10 mm Hg).
3. To determine whether any patient characteristics (age, sex, race, height, weight, BMI, arm circumference, ankle circumference, presenting complaint, and tobacco usage) influence the difference between ankle and arm NIBP measurements.

Chapter 2 LITERATURE REVIEW

Introduction

Blood pressure was first measured in 1733 by Rev. Stephen Hales on unanaesthetised horses by seeing how high blood rose in a glass tube inserted into the carotid artery [18]. In 1828, Poiseuille, in his medical school thesis describing his law for fluid flow, described the units millimetres of mercury (mmHg) that we use to measure blood pressure today [19]. Hales had initially measured the sap pressure in plants with a U-tube manometer but it was Poiseuille who then started to measure the aortic pressure in dogs by using a mercury-filled U-tube [18].

In developing the concept of measuring blood pressure indirectly, Marey was first to experiment with “counterpressure” in 1876. He created a closed system by sealing an assistant’s hand and wrist in a water-filled jar and measuring the amount of external pressure (counterpressure) required to blanch the hand [20]. Shortly after that, pneumatic external pressure cuffs were applied to various areas of the upper limb in order to evaluate the “counterpressure” response using this method. Riva-Rocci (1896) and Hill and Barnard (1897) initially used bicycle wheel inner tubes for cuffs, but Von Recklinghausen (1906) found that the cuffs were too narrow and gave falsely elevated pressures [20].

The automated oscillometric method for blood pressure determination was proposed by Ramsey in 1976 [21] and commercialised in 1979 [22]. Initially only MAP was able to be measured, but subsequent technological advancements led to the development of formulae to analyse the oscillations obtained in order to derive the SBP and DBP.

Meaning of the different pressures

Blood pressure is the pressure of the blood exerted against the walls of the arteries. The arterial pressure is conventionally written as systolic pressure over diastolic pressure and measured in millimetres of mercury (mmHg) [23].

Systolic blood pressure (SBP)

This is the maximum or peak pressure within the arteries measured when the heart is contracting (during systole) [24].

Diastolic blood pressure (DBP)

This is the minimum or lowest pressure within the arteries during diastole [24].

Pulse Pressure (PP)

This is the difference between the systolic and diastolic pressures [23].

Mean Arterial Pressure (MAP)

This is the average pressure measured throughout the cardiac cycle [23]. As the cardiac cycle is not constant i.e. about one third of the cycle is spent in systole and two thirds of the cycle is spent in diastole, the mean arterial pressure is slightly less than the average of the systolic and diastolic pressures. This is also contingent on the heart rate being normal (60–100 bpm). As the heart rate increases, so the percentage of time spent in systole increases [25].

It can be approximated by the following equation:-

$$MAP = DBP + \frac{PP}{3}$$

Equation 2.1 The equation to calculate mean arterial pressure

Autoregulation of perfusion is regulated by the mean arterial pressure. It is the determinant of blood flow at a capillary level. At a MAP of less than 60 mmHg, autoregulation of perfusion fails [26].

Methods of Blood Pressure measurement

Invasive

The gold standard for obtaining arterial blood pressure is via direct measurement with an intra-arterial catheter [5]. Blood pressure measurements can be obtained invasively by placing a small catheter into an artery (usually the radial artery) and coupling that to a transducer connected to a monitor which can continuously show the waveforms of the pressure readings obtained from the artery. Once this closed system is calibrated at the level of the right atrium (zeroed), it is thought to display an accurate systolic and diastolic pressure with a calculated mean arterial pressure.

This system has the advantage of being able to supply a direct measurement of the systolic and diastolic blood pressures. Unfortunately, the time taken for insertion generally makes it unsuitable for ED usage in the acute resuscitation setting. The invasive nature and inherent complications including arterial pseudoaneurysm formation, nerve damage and potential limb threat make it unacceptable for general ED use.

The presence of beat-to-beat variability makes it difficult to compare the readings obtained to a static, non-invasive measurement.

Non-Invasive

Manual/Semi-automatic Auscultatory

Manual NIBP techniques have been the main method of obtaining a measurement of blood pressure. In order to improve accuracy, semi-automatic machines were invented in the hope that a set cuff pressure deceleration rate would prevent some of the errors that are inherent to manual cuff pressure usage.

Mercury

The mercury manometer is still the gold standard for NIBP measurement [6, 27]. This might not be the case in a few years as fears over the toxic nature of mercury are forcing its removal from medical practice. Although the elemental mercury enclosed in manometers has rarely been reported to cause health problems, the long-term exposure to mercury compounds has been [28]. The search for newer accurate devices continues, but to date there is no equivalent.

Aneroid

Aneroid sphygmomanometers have gained popularity as a potential replacement for mercury. They work via a mechanism of gears, coiled springs and diaphragms through which air is pumped. The reading is then obtained by this mechanism being linked to a pressure indicator. These intricate moving parts are not only vulnerable to metal fatigue but also to breakage from “trauma” (e.g. dropping) [29]. It is recommended that these machines are calibrated every six months to ensure accuracy. Unfortunately, it has been shown that unless this is routinely performed, even aneroid machines in apparent good working order will display inaccurate readings which are clinically significant (≥ 10mm Hg) [30]. The fragile nature of this system and high maintenance makes it unsuitable for routine use in a busy, chaotic ED.

Automatic

There are two main types of automatic sphygmomanometers – the automated auscultatory and the oscillometric machines. The automated auscultatory machines consist of blood pressure cuffs which have microphones embedded in them to detect Korotkoff sounds [31]. This method is no longer commonly used.

Oscillometric

The concept of blood pressure measurement via oscillometry was originally described by Marey in 1876 [32]. An instrument for its use in the clinical setting was only developed commercially by Ramsey (released by the Critikon company) in the late 1970s with the invention of the DINAMAP™ – Device for Indirect Non-invasive Automatic Mean Arterial Pressure. [22, 31].

Oscillometry works by measuring the peak amplitude of the pressure oscillations transmitted from a vessel that is initially occluded by a cuff and then released – a characteristic pattern is produced.

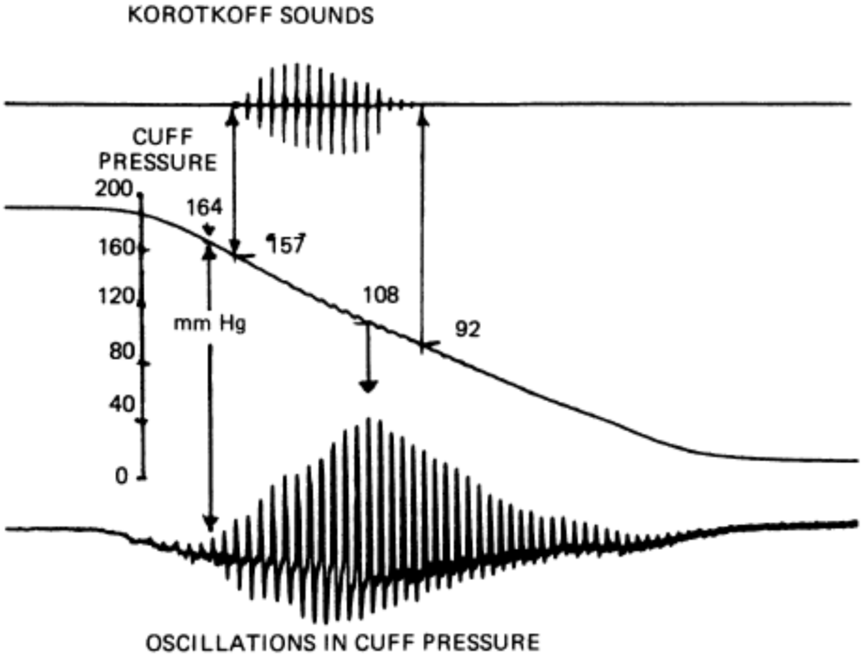

Figure 2.1 Oscillometry pattern observed with BP reading

Reproduced with permission from *Pickering TG. Blood pressure variability and ambulatory monitoring. Curr Opin Nephrol Hypertens. 1993 May;2(3):380-5* [33].

The peak of these oscillations corresponds to the MAP [22, 32] (108mmHg in Figure 2.1 above). The impact of Ramsey's invention has been substantial with DINAMAP™ equivalents pervasive in clinical practice. It is interesting to note that the original validation of his machine was done with only 17 subjects [22].

Subsequently, it was suggested by Geddes *et al*. [34] that due to the consistency of this characteristic pattern, that it would be possible to derive both systolic and diastolic pressures. In dogs and humans, it was seen that the systolic pressure was when the oscillations were half of the maximum amplitude and the diastolic pressure was 75-80% of the maximum. There was unfortunately a wide inter-subject variability of 10-20% difference between the actual and the oscillometry-estimated values [34].

Manufacturers of oscillometric sphygmomanometers make use of various ratios linked to the characteristic pressure oscillation pattern and patent their own proprietary algorithms in order to derive the SBP and DBP. The formation of this pattern is influenced by heart rate, pulse pressure, arterial elasticity and compliance of the cuff [32, 35].

The oscillometric method has the advantage of eliminating inter-observer variability but lulls the observer into a false sense of apparent precision due to the resultant blood pressure readout being presented digitally [36].

How to measure Blood Pressure

In most of the texts written on “How to measure blood pressure”, the main aim is to obtain the most accurate reflection of a patient’s blood pressure in order to diagnose hypertension. This is in contrast to the use of this measurement in the ED. In this acute care setting, the main aim of performing the task is to obtain a “vital sign” at patient presentation and perhaps make a judgement about a patient’s haemodynamic status rather than looking for the presence or absence of hypertension [6]. Therefore, many of the intricacies of strict blood pressure measurement are not followed – this may be born out of necessity or more likely practicality. Notwithstanding this, high BP readings in the ED often do predict hypertension on subsequent investigation, and so warrant referral for follow-up [17].

Table 2.1 Procedure to measure BP using the manual and automated techniques in order to diagnose hypertension.

Adapted from Perloff *et al.* [5]

	MANUAL	AUTOMATED
EQUIPMENT	• Mercury/aneroid manometer (placed at eye level to avoid error of parallax) • Stethoscope • Appropriate size cuff	• Oscillometric manometer • Appropriate size cuff
PERSONNEL	Person trained in the use of the techniques	
PATIENT	• Patient seated (back supported) • Arm at level of heart (± 4th intercostal space) • Arm supported • Measurement done after at least 1 minute rest • No prior exertion, coffee intake etc. • Quiet environment	
TECHNIQUE	1. Apply cuff to patient's bare arm	
	2. Inflate cuff whilst palpating radial pulse. Note the level of pressure at which the pulse disappears and subsequently reappears on cuff deflation.	2. Press start on the device
	3. Place the head of the stethoscope lightly over the brachial artery.	3. Record the systolic, diastolic and mean arterial pressures
	4. Inflate the cuff bladder to a pressure of 20-30 mmHg above the figure obtained on palpation.	4. Document the date and time of measurement, the arm on which the measurement was made, the patient's position and the cuff size.
	5. Deflate the cuff bladder at a rate of 2 mmHg/second whilst listening for the Korotkoff sounds (see below)	
	6. Record the systolic and diastolic pressures rounded off upwards to the nearest 2 mmHg	
	7. Document the date and time of measurement, the arm on which the measurement was made, the patient's position and the cuff size.	

Table 2.2 Korotkoff auscultatory sounds.

Adapted from Beevers *et al.* [37]

Phase I	The first appearance of faint, repetitive, clear tapping sounds which gradually increase in intensity for at least 2 consecutive beats is the systolic blood pressure
Phase II	A brief period may follow during which the sounds soften and acquire a swishing quality
Auscultatory gap	In some patients, sounds may disappear altogether for a short time.
Phase III	The return of sharper sounds, which become crisper and regain, or even exceed, the intensity of phase I sounds.
Phase IV	The distinct, abrupt muffling of sounds which become soft and blowing in quality
Phase V	The point at which all sounds finally disappear completely is the diastolic blood pressure.

Errors in Blood Pressure measurement

As will be discussed under the sub-heading "Clinically relevant differences", despite the fact that the vast majority of the errors in blood pressure measurement reach statistical significance individually, they are not clinically significant. However, it must be said that two or more of each of them may occur during the measurement of any one blood pressure which would then have a compounding effect on the inaccuracy of the ultimate measurement obtained.

Errors due to cuff size

As was recognised early on by Von Recklinghausen, a one-size-fits-all approach cannot be used with respect to BP cuff and bladder size [38]. The bladder must be of an appropriate size relative to the limb where the measurement is being taken. “Miss-cuffing” [39] can result in errors of over- or underestimation of BP. A cuff with a bladder that is too small (under-cuffing) will result in an overestimation of the BP (3.2/2.4 mmHg to 12/8 mmHg) whereas a cuff with a bladder that is too large (over-cuffing) will result in an underestimation of the BP (10 to 30 mmHg) [40]. It is therefore suggested that the “ideal” cuff should have a length that is 80% of the arm circumference and a width of at least 40 % of the arm circumference (length-to-width ratio of 2:1) [6]. By comparing intra-arterial and auscultatory blood pressure, Marks and Groch found that the optimum cuff ratio was a width of 46% of the cuff circumference. This ideal is not practical for the larger cuff sizes which would result in widths of 20 to 24 cm [41]. In practice, the cuff size recommendations even vary between different cardiovascular or hypertension societies.

Table 2.3 British Hypertension Society recommendations for cuff sizes [40]

Cuff Size	Description	Cuff Dimensions
Standard cuff	Adult arm	12 x 26 cm
Large cuff	Obese arm	12 x 40 cm
Small cuff	Lean adult/children	12 x 18 cm

Table 2.4 American Heart Association recommendations for cuff sizes [5]

Cuff Size	Arm Circumference	Cuff Dimensions
Small adult cuff	22-26 cm	10 x 24 cm
Adult cuff	27-34 cm	13 x 30 cm
Large adult cuff	35-44 cm	16 x 38 cm
Adult thigh cuff	45-52 cm	20 x 42 cm

Furthermore, individual manufacturers have differences in the recommendations for cuff sizes to be used. The GE Healthcare Carescape V100, which was used in this study, advocates the following when choosing cuff size: -

Table 2.5 Cuff size recommendations for the GE Healthcare Carescape V100

Arm Circumference	Cuff Size	Cuff Dimensions
17 – 25 cm	**Small adult**	12 x 22 cm
23 – 33 cm	**Adult**	16 x 30 cm
31 – 40 cm	**Large Adult**	16 x 36 cm
38 – 50 cm	**Adult Thigh**	16 x 42 cm

The manual warns that the “size, shape, and bladder characteristics can affect the performance of the instrument” [42].

Under-cuffing is the more common problem. This is due to a combination of the lack of availability of the right size cuff [43] as well as users being required to first measure the arm circumference prior to applying a cuff, which is often not done in practice [40].

Although oscillometric blood pressure was first used to measure ankle blood pressure by Adiseshiah in 1987 [44], there is still no evidence to support which cuff should be used in the ankle. The assumption that the same circumference as well as bladder widths used around the arm will apply to the ankle is unproven.

There is no consistency in the data on application site, wrapping technique or cuff bladder size to be used on the ankle.

Errors due to cuff placement

The standard cuff placement for measurement of blood pressure is on the arm with the reaction of the brachial artery to compression measured [6]. In the arterial tree, the general principle is that as the distance from the heart increases, so the measured systolic pressure increases. This is in contrast to the diastolic pressure measurement which decreases the more distal from the heart it is measured. The measured MAP decreases by only 1 to 2 mmHg from the aorta to the peripheries [6]. There is regrettably seemingly no consistency to the level of increase or decrease of the SBP and DBP that can be consistently linked to the cuff placement site as it is moved further away from the heart.

Errors due to developmental stage – Children vs adults

The so-called “normal” increase in BP measured at the ankle compared to the arm also seems to be erratic when applied to children. In attempting to determine a normal ABI, Katz *et al.* found amongst 350 patients aged 2 weeks to 2.5 years that only after the second year of life did the ABI approach adult values of 1.1. Children younger than that had ABIs 0.9 to 1 meaning that the brachial and ankle BPs were either the same or that the arm was higher by 10% [45]. This is contrary to the “normal” adult findings. This was similar to the findings of Crapanzano *et al*. in which patients less than 6 months old had calf BPs that were lower than the arm, which equalised at 6 months and continued increasing until adults levels were reached at approximately 18 months [13]. Sadove *et al*. reported that leg pressures exceed arm pressures for the first week of life and thereafter are essentially equal [46]. Both Crossland *et al*. and de Swiet *et al*. found average differences in neonates where the upper limb BP was up to 20 mmHg greater than the lower limb BP [47, 48].

These findings are contradicted by Park *et al*. who found that the blood pressure in the lower limb, measured invasively, was between 12.8 and 37.4 mmHg higher than the upper limb [49].

Conflicting data has been found in the paediatric population with regard to cuff placement. In children under 8 years of age undergoing anaesthesia, it was found that the BP measurements in the leg with the child in the supine position was in fact consistently and clinically significantly lower than in the arm. The MAP in children up to 4 years old had a difference of 10 mmHg between the upper and lower limbs [12]. Despite the reverse expectation, a result incorrectly showing lower blood pressures in the ankle compared to the arm is equally dangerous. In a similar age range (1-8 years old) but a 4-fold larger sample size, Schell *et al*. found that the measured calf BPs were invariably higher than in the arm but this was inconsistent. Calf SBP was higher in 73% of cases, calf MAP was higher in 58% of cases and calf DBP was higher in 53% of cases [50]. Confounders for these results extend to the methodology whereby the head of the bed was elevated 30 degrees and the extremities were resting on the bed (see arm position and body position below). Crapazano *et al*. compared calf and arm blood pressures in children 2 weeks to 3 years of age. The comparison showed no link between the 2 regions. Interestingly, the SBP tended to be lower in the ankle than the arm in infants less than 6 months old [13].

Errors due to cuff wrapping and padding

It is recommended that the cuff be “pulled snugly” around the “bare” arm in preparation for measuring the blood pressure [6]. Nuessle showed that applying the cuff loosely led to a falsely high manual blood pressure [51]. In attempting to simulate the obese patient, King measured the blood pressure manually after wrapping cotton and sponge rubber around the arm [52]. He found that this also led to falsely high blood pressure readings. The oscillometric method seems to have negated the effects of padding as was seen in the study by Kahan *et al*. where they compared measurements obtained on the bare arm, below a rolled-up sleeve and over a sleeve. The padding effect of the sleeve only seemed to cause a clinically important alteration to the measurements of patients with SBP > 140 mmHg [53]. In a study to evaluate whether the use of padding for its skin- and nerve-protective properties would alter the reliability of blood pressure measurements in anaesthetised patients, it was found not to compromise the reliability of the blood pressure readings [54].

Despite variations in body mass index (BMI) causing changes in arm circumference, the arm itself generally remains cylindrical in shape and thus the cuff can be wrapped with some consistency straight around the arm without any gaps. On the other hand, the ankle morphology varies depending on BMI and genetic variants. Thus the ankle morphology can range from a cylindrical shape to a tapering shape. The technique of cuff-wrapping around the ankle can therefore also have an effect on the measured blood pressure.

Contour/spiral wrapping gives a closer fit to the tapering cylindrical shape of the leg but leads to large variation in ankle BP measured manually via Doppler techniques [55]. This method of cuff wrapping has been advocated by Mundt *et al*. with an oscillometric device because of its high repeatability and ease of operation [56]. This was contradicted by Takahashi *et al*. in their comparison between the oscillometric and intra-arterial blood pressures. Although the average difference in ankle SBP between the straight and spiral/contour wrapping methods were the same, the inter-observer reliability was better with the straight method [57]. The accuracy of the indirect measurement of BP by both wrapping techniques did not improve the accuracy of the overall measurement. However, these measured values were compared to invasive blood pressure which has the problem of beat-to-beat variability.

Errors due to limb position

Errors due to limb position – Arm

Instructions on "How to measure blood pressure…" advise that the arm position should be at the "level of the heart/right atrium" [37, 58]. In the ESH guidelines it stipulates that this level is denoted by the mid-sternal level [40] whereas in the

Framingham study[2], blood pressure is measured with the arm at desk level [58, 59]. The difference between desk level and heart level can vary between 6 to 23 cm [58]. The hydrostatic effects of this height difference can lead to as much as a 0.74 mmHg rise of BP reading for each centimetre the cuff is below heart level [58]. At the extreme of 23 cm, this would lead to a clinically significant difference in measured blood pressure of 17 mmHg. This can also be seen in the study by Guss *et al*. comparing perpendicular and parallel arm positions relative to the body where average SBP differences of 7.1 to 15.3 mmHg and average DBP differences of 8.1 to 16.4 mmHg were found [60].

Whether the arm is dependent or supported can also affect the reading of the blood pressure due to hydrostatic pressure effects. This occurs when the patient is both sitting and supine. In the sitting position, the blood pressure readings are lower when the arm is supported at heart level than when it is allowed to hang vertically i.e. dependent [61, 62]. In the supine position, failing to support the arm at “heart level” and allowing it to rest on the bed can result in an increase in the blood pressure of up to 5.5 mmHg [63]. Although statistically significant, this clinically insignificant change will not bring about a change in practice so that supine patients will have their arms supported by a pillow as it is not a practical to implement.

Errors due to limb position – Leg

For blood pressure determination, most guidelines recommend that both the patient’s feet should be kept on the floor [6, 16] whereas others do not specify [40].

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[2] The Framingham Study is an on-going, long-term study on the the epidemiology of hypertensive or arteriosclerotic cardiovascular disease in the consenting residents of Framingham, Massachusetts which started in 1948.

Adiyaman showed that there was no significant increase in blood pressure when legs were crossed at the ankles, but that blood pressure was affected statistically significantly when they were crossed at the knees (SBP differences of 2.7 to 7.9 mmHg) [64]. The changes are more pronounced in known hypertensive and diabetic patients. However, this is not a clinically significant amount. This was also the case in a study by Pinar *et al*. with statistically significant increases in mean SBP and DBP measurements of 8.49 mmHg and 5.71 mmHg respectively yet when the 95% confidence intervals are examined, these numbers exceed clinical significance at a potential difference of 23 mmHg and 18 mmHg respectively [65].

Errors due to body position and posture

The patient's body position can also affect the measured BP. Blood pressure measurements are similar in patients whether they are sitting or standing (unless they have postural hypotension) whereas there is a 5 mmHg increase or decrease in blood pressure when those same patients have their BP measured in the supine position [66]. Although not reaching clinical significance, this change in body posture is a factor to note if comparing a patient's blood pressure on different occasions.

There is even a difference in the BP measurements of sitting patients when sitting with their back supported or unsupported. The seated patient can have a measured diastolic BP of up to 6.5 mmHg higher if sitting upright when compared to sitting with their back supported [67].

When the measured blood pressures between the sitting and supine patient are compared, there have been a variety of differences noted. In the study by Netea *et al*., the subject's body posture influenced the diastolic blood pressure and heart rate, both of them being significantly higher with patients sitting rather than supine [68]. Again, this reached statistical significance, with the actual diastolic BP difference of 5 to 10 mmHg not being clinically significant. In a similar study by Terent and Breig-Asberg with 401 patients, there was no difference in the diastolic pressures between the sitting and the supine patients, but there was an 8 mmHg increase in systolic BP in the supine patient group [69].

In various degrees of the lithotomy position ranging from low to exaggerated, Halliwell *et al*. demonstrated that the measured blood pressure in the lower limb decreased by up to 40 mmHg as the legs were raised increasing the vertical distance above the arm. This reinforces the findings on the effects of hydrostatic pressure and limb position on the BP measurement [70].

Errors due to terminal digit preference bias

A terminal digit preference is common amongst blood pressure observers – with a disproportionate amount of readings ending in 5 or 0 [71]. This contributes to inter-observer error of as much as 5 to 10 mmHg [72]. This is further compounded by the fact that the number 5 should not be used when recording manual blood pressures as it is an odd number which does not feature on the manometers and is therefore an estimate. Zero as a terminal digit should only occur 20% of the time [7]. Blood pressure is required to be measured in 2 mmHg decrements. Terminal digit preference bias is eradicated by the digital readouts of the oscillometric sphygmomanometers.

Errors due to pre-measurement rest period/preparation

Variability in the patient’s blood pressure can be influenced by physical activity preceding BP measurement, coffee or alcohol ingestion, eating, talking, bladder distension, pain and/or anxiety [5, 6]. Ideally, a patient should be told to relax for at least 5 minutes before the blood pressure is measured. This can be reduced to a minimum of 1 minute if necessary. Although some of these prerequisites are possible, the luxury of fulfilling them is not available in the majority of cases because of patient acuity or even sheer patient numbers presenting for care in the ED. One of the most common reasons that patients present to the ED is due to pain which may cause an elevation in the patient’s BP [17]. Anxiety, which may or may not be linked to pain, as a physiological “fight or flight” reaction in response to seeing a doctor, may increase blood pressure by as much as 30 mmHg. This is commonly referred to as the “white-coat effect”. This can occur in both normo- and hypertensive patients [40, 73].

Errors due to location (area in hospital vs pre-hospital)

It is advised that blood pressure should be measured with the patient in a quiet environment where the room temperature is comfortable [6]. In acute medicine, these are further factors which cannot be controlled.

There are very few so-called “quiet” areas in a busy ED. On entering the ED environment, patients should undergo a triage evaluation in order to establish the acuity of their presenting complaint. High ambient noise does not make this an "ideal" environment for BP measurement. In a cohort of 171 patients presenting to an ED, Cienki *et al*. demonstrated that there were significant discrepancies in the values obtained in triage compared to the reference standard. "Triage hypertension" of more than 15 mmHg was detected in almost one third of patients with an average difference in SBP of 12 mmHg and DBP of 9.9 mmHg [74]. This may falsely inflate the BP measurement of not only the hypertensive, but also the hypotensive patient perhaps erroneously making their acuity less and delaying life-saving interventions.

Errors due to cuff inflation/deflation rate

Inflation rate has no significant effect on blood pressure measurement [75] whereas deviation faster or slower than the recommended rate of deflation (2-3 mmHg/s) will affect both the systolic and diastolic readings obtained via manual BP measurement. Zheng *et al*. showed a statistically significant underestimation of SBP and an overestimation of DBP when the rate of cuff deflation was increased, yet these were only 8 and 6 mmHg respectively. They also compared the effect of an increased deflation rate via the oscillometric method. This had no effect on BP measurement [76].

Errors due to human resources

Accuracy of manual BP measurement is dependent on a person's ability to perform this complicated (to the uninitiated) procedure accurately. Although training videos, manuals, computer-based learning and direct instruction are potential methods of teaching, the phasing-out of mercury manometers, the intrinsic fallibility of aneroid manometers and the arrival of automated oscillatory devices make this a more difficult skill to teach or acquire [37]. The ease of training to use automated oscillometry makes it an enticing alternative option when the ignorance of its fallibility is unknown to the majority of healthcare workers and laypersons.

Errors due to artefacts and patient factors

Table 2.6 Errors due to artefacts and patient factors

ARTEFACT	EFFECT
Arrhythmia	Arrhythmias (e.g. atrial fibrillation) lead to a large variability in the BP from beat-to-beat. Many oscillometric machines are unable to accurately determine BP in the presence of an arrhythmia [77]. If there is a bradyarrhythmia, the deflation rate for manual BP determination should be slower than normal otherwise there will be an underestimation of the SBP and an overestimation of the DBP [40].
Shivering, patient movement and vibration	As oscillometric BP relies on the pressure pulsations of the oscillations, patient movement e.g. shivering [78] or external movement e.g. vibration from a helicopter can interfere with the measurement.
Pregnancy	During manual BP measurement, the disappearance of the Korotkoff sounds (phase V) may not occur, thereby requiring the use of the phase IV muffling to be used in order to measure the DBP [40].
Hypothermia, shock and/or vasoconstriction	Auscultation of the Korotkoff sounds, palpation of the radial/brachial pulse or oscillometric measurement may be difficult and unreliable in patients with generalised vasoconstriction [5]. This does not seem to apply in inotropically-induced vasoconstriction [79].
Infants	It may be difficult to hear the Korotkoff sounds in children under 1 year of age thereby leading to an underestimation in the true SBP [80].
Obesity	BP errors in obese patients mainly relate to the shortcomings in obtaining a correct cuff size. This is further compounded by the underestimation that occurs by non-invasive (manual and oscillometric) BP methods compared to invasive BP readings [81].
Atherosclerosis	“Stiff arteries”/non-compressibility from atherosclerosis in the elderly may lead to errors in the oscillometric technique [28].

Errors due to inadequate maintenance

Calibration of manometers should occur at the following intervals: -

Table 2.7 Frequency of calibration for manometers

MANOMETER	FREQUENCY OF CALIBRATION
Mercury	Annual [28, 43]
Aneroid	Bi-annual [43, 82]
Oscillometric	As per manufacturers recommendation Hospital policy commonly annually [43, 83]

The accuracy and usefulness of the equipment for blood pressure determination depends on their regular maintenance. Some hospital audits have shown the almost half of the manual sphygmomanometers were not in working order [83]. Although servicing and calibration recommendations on automated manometers are commonly not followed, they are more likely to be in working order compared to non-calibrated manual machines [83]. Only once the Mayo Clinic instituted strict maintenance and calibration protocols for their aneroid sphygmomanometers did their instrument failure rate drop to less than 0.5% [84].

Accuracy of Blood Pressure measurement

The importance of accuracy in blood pressure measurement can be demonstrated by the following example regarding the diagnosis of hypertension: -

Using the current JNC VII [16] criteria for the diagnosis of hypertension, if a systematic error led to the underestimation of the true blood pressure by 5 mmHg, it would mean that 21 million people who would benefit from anti-hypertensive drug treatment would be mislabelled as having “high normal” blood pressure and conversely, an overestimation of 5 mmHg would mean that 27 million people would be misclassified as being hypertensive exposing them to the expense and potentially adverse effects of anti-hypertensive medication that they would not require [28].

Even though a single inaccurate reading of 5 mmHg does not seem to affect the individual patient, with most texts using at least 10 mm Hg as a clinically relevant difference [15, 85-87], the knock-on effect from a public health point of view is massive with either unnecessary over-treatment or lack of treatment.

Validation of blood pressure devices was instituted by the Association for the Advancement of Medical Instrumentation in 1987 when they published a standard for electronic and aneroid sphygmomanometers [40]. This was then followed by the British Hypertension Society (BHS) in 1990. Although having a common objective, these societies had slightly differing details with regards to specifications. After further study on the subject and the dissolution of the BHS working party on blood pressure, the Working Group on Blood pressure measurement from the European Society of Hypertension (ESH) developed an international protocol in order to be applicable to the majority of blood pressure devices available [40]. Guidelines are provided regarding the validation of the actual procedure, observer training, measurement validation, subject selection and accuracy criteria.

Accuracy (difference between the test and control) are categorised into 4 groups [40]:-

Table 2.8 Categorisation of blood pressure accuracy

Difference	Categorisation
0-5 mmHg	Measurements considered to be very accurate (no error of clinical relevance)
6-10 mmHg	Measurements considered to be slightly inaccurate
11-15 mmHg	Measurements considered to be moderately inaccurate
> 15 mmHg	Measurements considered to be very inaccurate

Validity of Blood Pressure devices

Blood pressuring measuring devices are used in the hospital and home environments. Device accuracy is generally assumed but commonly not validated. In 2003, the dabl® Educational Trust Limited was established by Rickard and O'Brien to oversee an educational website that would be a not-for-profit venture [88]. Its aim was to improve blood pressure measurement by providing independent evaluation of the devices on the market and standardisation of validation methodology based on current literature. The advisory board consists of international experts in blood pressure measurement [88]. Despite this, Sims *et al*. found that the majority of BP machines available in the European Union market in 2005 had not been validated by clinical trials [89].

The accuracy (agreement with the “gold standard”) of the device and validity of the measurements should be taken into account when a new device is purchased.

Inter-device variability

Whilst the validity of the individual machine is scrutinised, what about the difference in measurements between devices? Can the BP obtained at triage be compared to the BP obtained in the resuscitation area with different manufacturer's device? According to Kaufmann *et al*. these readings can probably not be used interchangeably [87]. They evaluated the variability between two different machines – firstly validating the reproducibility of two DINAMAP™ machines and then comparing them to two other automated oscillometric machines. Differences of greater than 10 mmHg occurred in more than one third of the individual measurements [87]. In studying 19 different devices, Sims *et al*. found that the individual devices allowed the monitoring of a trend but that the differences between devices may be clinically significant [90].

Although this may be of concern, Thien *et al*. puts it in perspective by highlighting that in the Van Buuren *et al*. study amongst 12 general practitioners well-trained in measuring BP, the variation between doctors may be even greater than that between devices [91].

Clinically relevant differences

A standardisation of clinically relevant differences has not yet occurred therefore leaving it to the end-user to decide what would be clinically relevant in their environment and practice. Bur *et al*. and Gibbs *et al*. used 10 mmHg differences in adults as being clinically significant. This was also used by Kaufmann *et al*. [79, 86, 87]. When evaluating the accuracy of BP in the forearm of adults, Schell *et al*. decided that a difference of more than 5 mmHg was clinically significant [92]. She used a range of 4-8 mm Hg in children in the paediatric intensive care when comparing the calf to the arm [50]. The opposite extreme was adopted by Sanghera *et al*. who considered a difference of greater than 20% (20 mmHg in a patient with a SBP of 100 mmHg) to be clinically significant [11] and Singer *et al*. who considered a difference of up to 20 mmHg as being acceptable [93].

Measurement effects of cuff placement

The problem in clinical practice is that the arm is not always freely available for blood pressure usage alone. This is apparent even more so in the ED where limited access can stem from injury (e.g. arm amputation) to urgent intervention requirements (e.g. the need to find an easily accessible place like the antecubital fossa in order to site an intravenous cannula in a patient requiring resuscitation).

It is this necessity which has brought about the desire to find an alternate but accurate site for blood pressure measurement.

Measurement effects of cuff placement – Arm-Ankle

If the arm is not available for attachment of a cuff in order to measure blood pressure, the ankle seems to be the next most logical and convenient choice. The measurement of blood pressure at the ankle (usually measured manually with a Doppler probe) is commonly used in the diagnosis of peripheral vascular disease via the ankle-brachial pressure index (ABI). Even from the outset, the oscillometric DINAMAP™ was touted to be able to measure ankle blood pressure accurately yet the initial validation was done with a series of 28 studies involving just 17 people [22]. Attempts have since been made to use arm and ankle blood pressure measurements interchangeably.

The potential conflict when analysing the available data comparing arm and ankle blood pressures is that the blood pressure used as the gold standard is inconsistent. Some studies compare oscillometry figures obtained to intra-arterial measurements with or without auscultatory comparison [44, 49] whereas others validate and compare them with oscillometry alone using the arm as the reference BP [11, 14, 15, 44, 94, 95].

The other problem is the lack of consistency in patient positioning when comparing these two different sites. Moore *et al*. compared arm and ankle with the head elevated 30 degrees and reported that the ankle BP can be considered useful despite an 8 mmHg higher BP. The limits of agreement were -8 to 24 mm Hg making the difference clinically significant for a significant proportion of patients [95]. Wilkes and DiPalma measured BP during colonoscopy and did not mention patient position. They showed both statistically and clinically significant differences in the MAP and SBP, yet advise that if an arm is not available that the ankle can be used knowing that the readings obtained are generally higher than the arm [14]. Block and Schulte also do not specify patient position, but do mention that hydrostatic pressure errors were corrected. They support the use of ankle MAP and DBP in place of arm measurements which is unusual as SBP had the higher correlation in other studies. They caution that peripheral vascular disease should be excluded or the ankle BP compared to the arm BP before complete reliance on ankle BP alone [15]. This is unfortunately not clinically realistic in the ED in a resuscitation setting. The luxury of time for comparison, interpretation and consideration is not available. If an accurate BP is required, perhaps this important step should not be left out.

In evaluating BP differences between the ankle and the arm in patients undergoing caesarean section, Sanghera *et al*. found ankle BP to be unreliable. Their patient population was evaluated in the horizontal supine and supine with 15 degrees lateral tilt positions. Although the average differences for SBP, MAP and DBP were below clinical significance, the limits of agreement were unacceptably wide. This would have resulted in hypotension being missed in 20% of the patient population which could have dire consequences if left untreated. This showed that the ankle position was not an alternate option in pregnant patients [11].

Adiseshiah *et al*. wanted to investigate whether oscillometry could be used to measure ABI. They started their investigation by validating their chosen oscillometric device compared to invasive, intra-arterial measurements. There was no significant difference between the invasive and oscillometric MAP and SBP but there was a significant under-reading difference in the oscillometric DBP. Although the intra-arterial and oscillometric SBP measurements had a strong correlation coefficient, the oscillometric device consistently under-read the SBP by 20% which was statistically significant ($p<0.001$) [44]. Despite this short-coming, they regarded the oscillometric device as an alternative to Doppler when measuring ankle blood pressures. This is because they wanted to calculate the ABI. The normal ABI is 1.1 (0.9 – 1.3) which clearly would mean that the normal ankle pressures measured must be higher than the arm in order to obtain a ratio of more than 1 [44]. This was the case in the validation of normal subjects in their study.

So ankle and arm are not interchangeable, but are linked by an average ratio of ankle:arm of 1.1 at rest and 0.9 post-exercise (possibly related to vasodilation) [44].

The comparison between arm and ankle blood pressure in patients in the supine and the reverse Trendelenburg position by Parry *et al*. demonstrated that even when hydrostatic pressures were taken into account the invasively measured pressure in the dorsalis pedis arteries was still higher than that expected to originate just from hydrostatic pressure [96].

Even slight changes in positioning of the ankle can cause statistically significant differences in the blood pressure readings. Anderson looked at moving the cuff slightly more proximally in order to avoid venous ulcers when measuring the ankle-brachial pressure index (ABI). He found that the proximal values were up to 4 mm Hg different but not clinically significantly different [97].

Measurement effects of cuff placement – Arm-Calf

Similar to the ankle, the comparisons between arm and calf have also shown varying results, inconsistent methodologies as well as various recommendations based on the findings.

In adults, compared at 30 degrees head tilt-up, similar to their ankle findings, Moore *et al*. showed that the MAP when measured at the calf was 3.7 mmHg higher than in the arm but with wide 95% limits of agreement (-12.3 to 19.7 mmHg). The DBP at the calf, however, was 3.7 mmHg lower than the arm also with wide 95% limits of agreement (-21.2 to 13.9 mmHg). The calf demonstrated a higher discomfort score when compared to the ankle [95]. By avoiding leg ulcers and placing the cuff more proximally in the leg, Anderson showed a statistical but not clinical difference of 4 mmHg in SBP but this was compared to the ankle as opposed to the arm. He also noted that a more proximal cuff position on the leg was more uncomfortable [97]. In a cohort of pregnant patients, Zahn *et al*. proposed that calf blood pressure may be preferable to arm BP during spinal anaesthesia as shivering would then potentially not affect the oscillometric measurement in the leg. Unfortunately, there was a poor agreement between the arm and cuff blood pressure making the calf unsuitable for use [10].

Measurement effects of cuff placement – Arm-Thigh

Evidence on measuring thigh blood pressures is limited potentially due to the inconvenience and difficulty in accessing the site in a supine patient. In 1924, Burdick *et al*. attempted to prove that there would be a “differential pressure in favour of the femoral” region. Through a membrane manometer, they showed that the systolic pressure measured at the popliteal artery after thigh compression was higher than in the arm with measured differences as high as 40 mmHg [9].

Measurement effects of cuff placement – Arm-Arm

The symmetry of the human body leads one to expect that the pressure in one limb would be the same as the pressure in its mirror-image counterpart unless there is a disease process e.g. peripheral vascular disease which affects the one and not the other.

Guidelines for hypertension diagnosis recommend that “BP should be measured in both arms” or that the BP should be “verified in the contralateral arm” and the arm with the higher blood pressure should be the one used for subsequent measurements [5, 16, 40].

A review of studies looking at inter-arm blood pressure differences showed a 19.6% prevalence of SBP inter-arm difference greater than 10 mmHg and 4.2% greater than 20 mmHg [98]. This review did not include work done by Chang *et al*. in 2003 which showed inter-arm agreement of within 4 mmHg for SBP and 3 mmHg for DBP [99].

In a study on oscillometric ABI determination, Kawamura compared the readings of arm and ankle BP in 247 patients – 80% normal individuals and 20% with peripheral vascular disease, only 10% of the normal and 4% of the affected group had equal blood pressure measurements in their upper limbs [100]. Fifty to 60% of the arm readings showed a higher SBP in the right arm of the normal group. Hypotheses for this difference include the cardiac systolic wave exerting a greater pressure in the first branch of the aortic trunk or that the majority of patients were right-hand dominant and therefore the limb with the greater strength that is more commonly used would have the higher arterial pressure measurement [100].

Measurement effects of cuff placement – Arm-Forearm

Regardless of BMI, forearm morphology remains relatively unchanged [101]. If the arm is not available for BP measurement, the forearm has therefore been proposed to be the next best option but again with conflicting results (see Table 2.9 below). Wrist position relative to the heart is even more paramount when measuring blood pressure at the wrist.

Table 2.9 Comparison between arm and forearm BP [3]

FOR **means that arm and forearm BP can be used interchangeably,**

AGAINST **means that arm and forearm BP should not be used interchangeably.**

AUTHOR	No OF PATIENTS	FINDINGS (mmHg) Average difference (95% CI)	FOR/AGAINST
Shahriari *et al*. [102]	72 adults	SITTING SBP 8-18 average difference DBP 5.9-8.2 average difference	Against
Schell *et al*. [103]	70 Adults 19-97 yo	SUPINE SBP -6.16 (-24.5 – 12.2) MAP -4.22 (-17.3 – 8.9) DBP -3.23 (-18.7 – 12.2) 30° ELEVATED HOB SBP -9.4 (-24.6 – 5.9) MAP -7.26 (-18.6 – 4.1) DBP -6.21 (-19.7 – 7.3)	Against

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[3] The abovementioned 95% CI in the table were calculated by the formula CI = Average difference ± (SD x 1.96) unless presented in the article. The results given were checked and rounded to 1 decimal place.

Schell *et al*. **[92]**	204 Adults and children 6-91 yo	SITTING SBP 1.31 (-17.1 – 19.7) MAP 1.02 (-13.9 – 15.9) DBP 0.87 (-14.5 – 16.2)	Against
Schell *et al*. **[104]**	221 Adults 18-93 yo	SUPINE SBP -8.3 (-27.6 – 11.0) MAP -5.3 (-17.3 – 6.6) DBP -3.8 (-15.1 – 7.5) 45° ELEVATED HOB SBP -13.5 (-33.4 – 6.4) MAP -10.6 (-23.5 – 2.2) DBP -9.2 (-21 – 2.5)	Against If used, careful documentation required – use trend rather than single readings.
Domiano *et al*. **[105]**	106 Adults 20-85 yo	SITTING SBP -4.3 (-31.2 – 22.6) DBP -2.4 (-19.5 – 14.7)	Equivocal If used, careful documentation required. Differences greatest in men, obese and middle-aged (36-65 yo) patients
Pierin *et al*. **[106]**	129 Obese adult BMI > 30	SITTING SBP 12 (-7.6 – 31.6) DBP 9 (-8.6 – 26.6)	Equivocal Corrected if arm circumference 32-44 cm
Palatini *et al*. **[107]**	85 Adults 18-76 yo	SUPINE SBP 8.2 (-10.8 – 27.2) DBP 9.2 (-3.3 – 21.7)	Against Differences greater in men
Mourad *et al*. **[108]**	50 Adults 41-73 yo	SITTING Horizontal arm position SBP 0.99 (-17.9 – 19.9) DBP 3.01 (-17.7 – 23.8) Dependent arm position SBP 12.10[4] (-16.8 – 40.0) DBP 9.25 (-8.0 – 26.5)	For If the wrist cuff is kept at heart level and the arm is not dependent

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[4] Average SBP presented in the article was calculated incorrectly.

Khoshdel *et al.* [109]	50 Adults 55-75 yo	SITTING Shoulder alignment SBP 13.31 (-7.2 – 33.9) DBP 15.97 (-2.9 – 34.8) Horizontal alignment SBP 7.09 (-18.5 – 32.7) DBP 11.85 (-7.0 – 30.7) Desk alignment (Heart level) SBP 3.78 (-19.8 – 27.3) DBP 9.41 (-8.8 – 27.6)	For Requires individual clinical validation – may need to make a 5-10 mmHg adjustment desk (heart level) position best
Singer *et al.*[5] [93]	151 Adults 19-51 yo	SITTING SBP 3.6 (-23.4 – 30.6) DBP 3.9 (-16.7 – 24.5)	For Advocates that a difference of up to 20 mmHg is considered acceptable

The wide CI seen in some of the studies means that there was a large variation between the differences thus making the data unreliable.

Measurement effects of cuff placement – Arm-Finger

The Finapres™ was designed as an alternative NIBP monitor that could potentially replace the need for an invasive intra-arterial line as it provides a continuous arterial waveform display of the MAP [86]. In comparison to direct, intra-arterial measurements, the overall bias approached zero but one third of MAP comparisons differed by more than 10 mmHg and approximately 5% differed by more than 20 mmHg [86]. Therefore although the overall bias was essentially perfect, individual reading disparities make its usefulness debatable.

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[5] The confidence intervals presented in the article were incorrectly calculated.

Ankle-Brachial Index (ABI)

One of the methods used to non-invasively determine whether a patient has peripheral arterial disease (vascular occlusion most commonly caused by atherosclerosis) is the ankle-brachial index. Normal values for this ratio are considered to be between 0.9 and 1.3. It is abnormal if the ABI ≤ 0.9. The incidence of peripheral arterial disease increases with age. The prevalence in patients older than 55 years old is approximately 16% whereas the incidence in patients older than 85 years old is approximately 22% [110]. By applying the normal ABI ratio to an arm SBP of 120 mmHg, the measured ankle blood pressure would be considered normal if it is anywhere between 108 and 156 mmHg i.e. up to a 36 mmHg difference which is certainly clinically significant in practice.

Diagnosis of hypertension

The Seventh Report of the Joint National Committee of Prevention, Detection, Evaluation, and Treatment of High Blood Pressure (The JNC 7 Report) provides a classification of BP for adults 18 years or older [16]. Based on the numbers and associated risk factors, recommendations are made regarding the most appropriate therapy to be instituted (see Table 2.10 below).

Table 2.10 Table of BP Classification (adapted from Chobanian *et al*.) [16]

Blood Pressure Class	SBP (mmHg)	DBP (mmHg)
Normal	< 120	< 80
Prehypertension	121-139	80-89
Stage I	140-159	90-99
Stage II	≥160	≥100

The utility of blood pressure in the ED

BP in the ED – Triage

Blood pressure is one of the first “vital signs” that “greets” a patient presenting to the ED. One of the determinants of a patient’s cardiovascular stability is graded according to the measured blood pressure. The South African Triage Scale makes use of the systolic BP alone with blood pressures of less than 100 mmHg and more than 199 mmHg garnering points to upgrade the patient’s acuity. The limitations of measuring BP specific to the ED include:-

- Time constraints (No opportunity for the patient to rest or no time to spare if the patient is critically ill or injured)
- High level of ambient noise (difficulty in auscultating for the Korotkoff sounds)
- The need for resilient equipment (high patient turnover means that equipment needs to be durable)

Cienki *et al*. showed that there were significant discrepancies in BP measurement between an oscillometric device from triage compared to a measurement taken inside the ED. Their main findings showed an over-estimation of the actual BP [74]. This could be detrimental to the hypotensive patient if they are triaged based on falsely inflated numbers which then misleadingly reassures ED staff. Fortunately, in most triage systems, BP is not the only parameter used to decide on a patient’s need for acute care.

BP in the ED – Resuscitation and monitoring of the hypotensive patient

Blood pressure is one of the key parameters in determining whether a patient requires resuscitation as well as monitoring the patient’s response to treatment interventions. The method used to measure the BP must be easily accessible, quick to perform and consistent. Portability is also essential because at times patients cannot be moved (e.g. a wall-mounted sphygmomanometer may not have tubing attached to the cuff that is long enough to reach the patient on a stretcher).

Hypotension (trauma-induced)

Shock is a clinical state of inadequate tissue perfusion with a relative or absolute inadequacy of cardiac output [23]. Shock commonly presents as hypotension. In the trauma patient, this is mainly related to hypovolaemia from acute blood loss [111]. The body compensates initially for this blood loss by vasoconstriction and tachycardia. A drop in blood pressure is a late sign usually meaning more than 30% of blood volume has been lost.

In comparing the accuracy of a manual to oscillometric BP in the trauma patient, Davis *et al*. discovered that hypotensive trauma patients (SBP < 110 mmHg) had their BP overestimated by the oscillometric device by 16-26 mmHg with the higher disparity occurring when the BP was less than 90 mmHg [112]. Their study was inspired by a patient that presented to them exsanguinating from multiple injuries including a traumatic near amputation. She arrived with a weak femoral pulse, tachycardia and decreased capillary refill. The manual systolic BP was 60 mmHg and the automated measurement registered 153/112 mmHg. This highlights that oscillometrically measured blood pressures (especially if reviewed in isolation or by inexperienced junior staff) are potentially dangerous in the emergency environment. They suggest using oscillometric BP determinations only after the patient's SBP is consistently greater than 110 mmHg.

There are alternate options or markers available in order to "measure" shock such as lactate, base deficit, central venous oxygen saturation, bioimpedance or arterial pulse contour analysis. Neither blood pressure nor any of the aforementioned modalities are perfect in their estimations of a patient's haemodynamic status.

Current recommendations for trauma patients with uncontrolled bleeding advise the practice of "hypotensive resuscitation" under certain circumstances i.e. keeping the BP low enough to prevent excessive bleeding and clot disruption yet high enough in order to maintain adequate perfusion to the vital organs. Oscillometric devices tend to overestimate low BP; therefore one may be falsely reassured by an overestimated "normal" blood pressure and not institute fluid resuscitation or inotropic support when it may in fact be required.

Hypotension (anaesthesia-induced)

In the controlled environment of an operating theatre (relative to the ED), Caramella *et al*. induced hypotension in a small group of 9 patients whose BP was monitored invasively by a radial arterial catheter. They showed that there was a good correlation between the invasive and non-invasive blood pressures during normotension, but that this was not the case when the patients were hypotensive. The correlation coefficient dropped substantially when hypotension was deliberately induced from normotension to BP 90/60 mmHg [113]. This was confirmed by Gourdeau and Martin the following year. Patients with deliberate hypotension (SBP < 80 mmHg) were more likely to have their BP overestimated by the oscillometric device whereas it was underestimated amongst patients with SBP greater than 80 mmHg [114].

BP in the ED – Resuscitation and monitoring of the hypertensive patient

Although the diagnosis of hypertension is important in the general population, in the ED high blood pressure is a critical management issue if the patient has a hypertensive emergency. This is a life-threatening elevation of the blood pressure which may be associated with myocardial infarction, stroke, pulmonary oedema, renal failure, aortic dissection or eclampsia in pregnant patients. In these instances, it is crucial that the blood pressure be decreased, but more importantly that it is decreased in a controlled fashion (not more than 25% of original MAP and DBP not below 110 mmHg) so as not to cause a watershed cerebral infarct.

Oscillometric blood pressure devices tend to underestimate high blood pressure. In a review of 30 studies by Braam and Thien, accuracy of BP decreased with increasing blood pressure values. With this in mind, non-hypertensive patients could be erroneously classified as hypertensive [115].

Summary

BP readings and interpretation are influenced by various factors:-

- Cuff size
- Cuff placement
- Developmental stage – Children vs adults
- Cuff wrapping and padding
- Limb position, body position and body posture
- Terminal digit preference bias
- Pre-measurement rest period/preparation
- Location (area in hospital vs pre-hospital)
- Cuff inflation/deflation rate
- Human resources
- Inadequate BP machine maintenance
- Inter-device variability
- Clinically relevant differences

Although the ankle may be considered a convenient alternative to the arm in the resuscitation of a critically ill or injured patient, its reliability as a valid alternative has yet to be consistently determined.

“The most important point is that the measuring accuracy in a single patient is unpredictable” [102]

Chapter 3 MATERIALS AND METHODS

Ethics

This research was approved by the Human Research Ethics Committee of the Faculty of Health Sciences of the University of the Witwatersrand (protocol approval number M10321 - see Appendix 1). Permission to conduct the study was obtained from the Netcare Group Ethics Committee (Appendix 2). Written informed consent was obtained from the patient prior to enrolment in the study (Appendix 3) after they were given an information sheet to read (Appendix 4).

Study Design

Prospective cross-sectional study

Site of Study

Netcare Union Hospital ED

Study Setting and Population

Adult patients presenting to the Netcare Union Hospital ED

Inclusion criteria:

> All patients from 18[6] to 50[7] years of age presenting to the ED who were not in need of emergency medical treatment and who consented to participating in the study

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[6] This is the age of majority in South Africa for consent. As was seen in the literature review, the blood pressure measurements in paediatric patients is considerably different to the adult.

[7] Patients older than 55 have a 16% risk of peripheral vascular disease. Patients with PVD could potentially confound the ankle vs arm comparison.

Exclusion criteria:

1. Failure to obtain consent;
2. Where informed consent could not be reasonably obtained because of the patient's medical condition;
3. Patients with a cardiac arrhythmia;
4. Patients known to have coarctation of the aorta, aortic dissection, arterial-venous malformations/shunts or congenital heart abnormalities;
5. Patients known to have unilateral neurological or musculoskeletal abnormalities,
6. Pregnant patients;
7. Patients known to have peripheral arterial disease or diabetes;
8. Inability to obtain the NIBP measurements e.g. lymphoedema secondary to breast malignancy, any limb amputation or significant limb injury.

Study Protocol

Data collection

Data was collected by the researcher. The information was recorded on a data collection sheet. Data collection was performed in a private cubicle with the patient in the supine position.

The following steps were followed:

1. Patients removed their shoes and heavy outer garments.
2. Patients were placed supine on the examination bed.
3. Demographic data was captured.

4. Patients rested for 5 minutes prior to initial blood pressure measurement.
5. Patients were instructed not to cross their legs[8].
6. Patients were asked to remain quiet throughout the procedure.
7. Both arms and legs were exposed sufficiently as would be required to take a blood pressure.
8. Correct cuff size[9] for arm and ankle was determined based on the circumference of the arm or ankle (see Table 2.5).
9. Blood pressure was measured at 4 sites – both arms and both ankles[10] according to a standardised system.
10. Order of measurements was determined by a random number table.
11. Measurements were taken sequentially with a 1 minute pause between each measurement.
12. The same machine was used for all patient and all measurements[11].
13. Patients' weight was measured on a combined scale and stadiometer. (Seca Model 703 1321009, GMBH & Co, Germany). Height was measured with a tape measure that was permanently mounted to the wall. Weight was measured to the nearest 0.1kg and height to the nearest centimetre.

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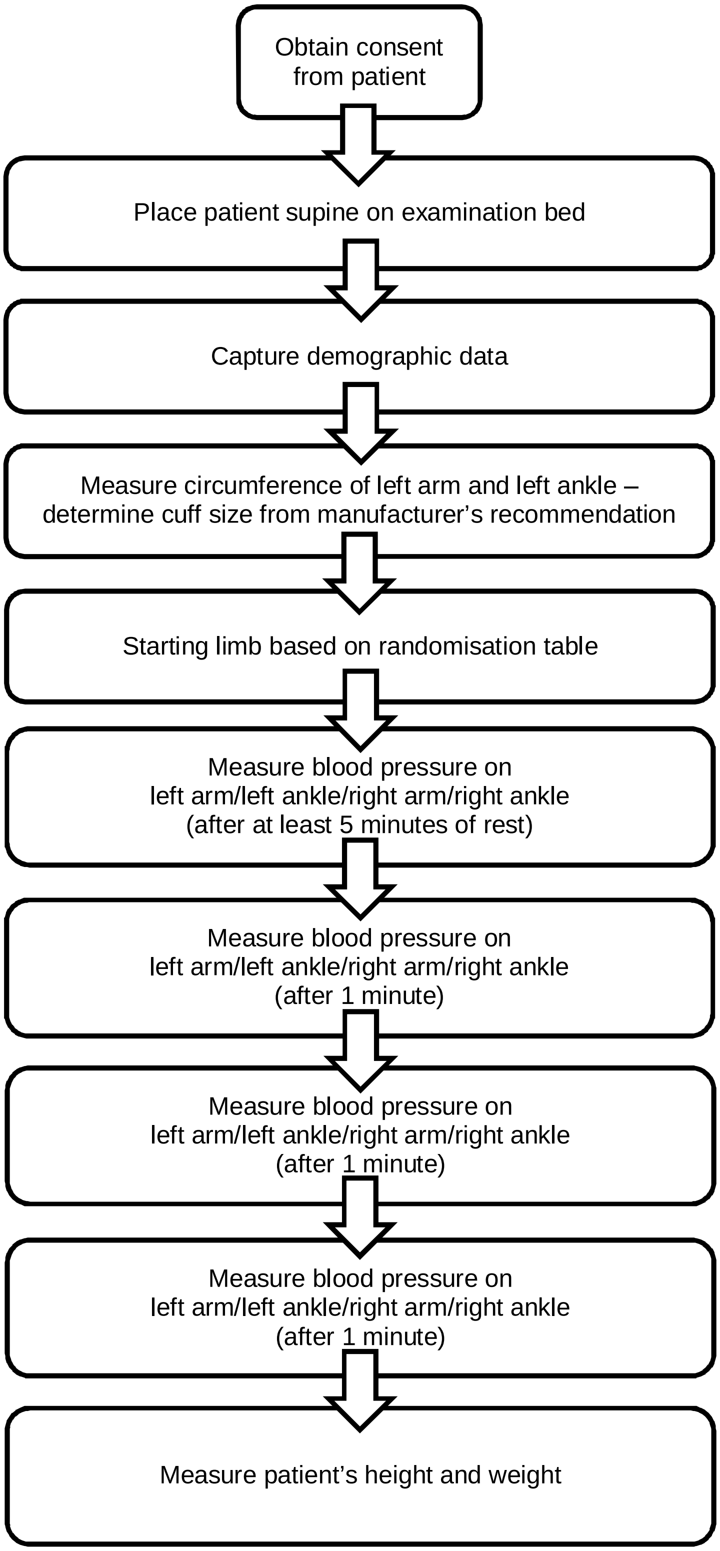
[8] In order to avoid any potential changes in blood pressure.

[9] The manufacturer recommended reference ranges were followed (see Errors in cuff size discussion above). In instances where there was cross-over e.g. arm size 25 cm, the larger cuff size was used as it was at the extreme of the reference range for the smaller cuff.

[10] Ankle was chosen because it was more convenient and more comfortable than the calf (Appendix 5).

[11] The machine was calibrated prior to the study (Appendix 7). Figures obtained are compared to self as opposed to other machines or a "gold standard" therefore inter-device variability is negated.

Figure 3.1 Procedure used for data collection



Sample Size Estimation

This study made use of a convenience sample of 201 adult patients from the ages of 18 to 50 years. This number of patients was determined by a sample size analysis using the following variables.

Power:	80%
Significance level:	5%
Difference in population means	10 mmHg
Estimated standard deviation	25 mmHg

Measuring Instrument

The blood pressure was measured by GE Healthcare’s Carescape V100 Vital Signs Monitor (Appendix 6). Calibration was performed prior to starting the study (Appendix 7). All the cuff sizes were available for use. Systolic, diastolic and mean arterial pressures were recorded as well as the patient’s heart rate. The machine was reset after each reading. Any difficulty in obtaining a reading was documented.

The cuff size was chosen based on the manufacturer’s recommendation (see Table 2.5).

Data Analysis

Descriptive statistics

Central tendencies of continuous variables were represented by means for parametric and medians for non-parametric data. Variability was reflected by standard deviation and/or 95% confidence intervals.

Data development

Disparities between two variables (e.g. arm and ankle SBP) were determined using three main methodologies:

- Residuals were determined using simple differences

$$Difference = Value\ a - Value\ b$$

Equation 3.1 Equation to calculate residual differences between arm and ankle BP

- Absolute differences were determined using a root mean square error transformation

$$Absolute\ difference = \sqrt{(Value\ a - Value\ b)^2}$$

Equation 3.2 Equation to calculate absolute differences between arm and ankle BP

- Percentage differences were determined from the root mean square error differences

$$Percentage\ difference = \frac{Absolute\ difference\ \times 100}{Value\ a}$$

Equation 3.3 Equation to calculate percentage differences

Subgroups

Subgroups were created within the data population according to clinically relevant values, as well as to obtain subsets with an approximately equal number of data points.

Statistical analysis

Previous studies comparing blood pressures at different sites have used a variety of methods in order to analyse the data. Table 3.1 shows the different methodologies used.

Table 3.1 Table showing the different methodologies of data analysis for comparing BP measurements

Study	Methodologies				
	Bland & Altman	**Correlation**	**Differences**	**Linear Regression**	**Other**
Adideshiah [44]		√	√	√	
Block [15]		√	√	√	
Chang [99]	√		√	√	
Domiano [105]		√	√		
Kaufman [87]	√				
Khoshdel [109]	√	√	√		Categorical analysis
Moore [95]	√	√			
Mourad [108]		√			least square / least product
Palatini [107]	√		√		
Pierin [106]		√	√		
Sanghera [11]	√				Misclassifications
Schell [92]	√		√		
Schell [104]	√	√	√		
Schell [50]	√		√	Multiple	Categorical analysis
Shahriari [102]	√		√		
Singer [93]		√	√		
Short [12]	√				
Wilkes [14]			√		
Zahn [10]	√		√		

The statistical analysis was focused to evaluate

- the degree of bias when comparing one measurement against another (average differences)

- the precision with which one measurement can predict another (average absolute and percentage differences)
- the overall similarity between two populations of measurements using error categories (differences within 5 mmHg, 10 mmHg, 20 mmHg or greater than 20 mmHg)

In line with previous studies, this study therefore made use of Bland and Altman[4], correlation, actual and root mean square differences, linear regression and categorical analysis.

The Paired t-test was used for comparisons of paired parametric data, and the McNemar test was used for paired categorical data. The t-test was used for unpaired parametric data and the Chi-square test for unpaired categorical data.

Pearson’s correlation analysis was used to identify significant correlations between the variables of interest.

The Bland and Altman technique is the gold standard technique for comparing two measurements and this was used according to standard methodology [4].

Standard linear regression methods were used to identify variables with significant predictive ability for arm SBP, DBP and MAP.

Based on the data, a simple “rule of thumb”, easy-to-use and easy-to-remember, formula was developed to provide a clinically useful correction for estimating arm

SBP and MAP from ankle SBP and MAP. This model was then tested using the same methodology as for the original data.

Significance level

Statistical significance at the 5% level (i.e. P-value less than 0.05) as well as clinical significance was investigated. A P-value <0.05 was considered to be significant for all statistical tests. Clinical significance was taken to be a difference of ≥ 10 mmHg.

Software

All data was captured from the data collection forms and entered onto an electronic spreadsheet (Microsoft Excel®, Microsoft Office 2007, Microsoft Corporation). All analysis of the data was conducted using Statistica® (Statsoft Version 10) www.statsoft.com.

Methodological limitations of this study

The blood pressure measurements were compared to the NIBP readings of the arm and not to the gold standard intra-arterial measurement.

Chapter 4 RESULTS

Basic demographic data

Two hundred and one (201) adult patients were enrolled in this study. There were 138 (68.7%) males and 63 (31.3%) females.

Table 4.1 Basic Demographic Data

Totals [N] are in square brackets

	TOTALS Average (95% CI)	MALE [138] Average (95% CI)	FEMALE [63] Average (95% CI)
AGE	34 (21 - 49)	34 (21 – 49)	35 (22 – 49)
RACE			
BLACK	127 (63%)	85	42
COLOURED	15 (8%)	8	7
INDIAN	8 (4%)	7	1
WHITE	51 (25%)	38	13
HEIGHT (cm)	171 (154 – 186)	175 (164 – 188)	161 (150 – 174)
WEIGHT (kg)	74 (52 – 109)	75 (53 – 100)	72 (46 – 111)
BMI (kg/m^2)	25.6 (18.1 – 36.2)	24.6 (18.2 – 33.1)	27.8 (17.9 – 41.5)
ARM CIRC. (cm)	29 (23 – 36)	29 (23 – 36)	29 (23 – 40)
ANKLE CIRC. (cm)	27 (22 – 34)	27 (22 – 32)	28 (23 – 35)
TRAUMA	136 (68%)	109	27
NON-TRAUMA	65 (32%)	29	36
TOBACCO USE [75]			
SMOKER[12]	35 / 75 (47%)	31	4
NON-SMOKER	40 / 75 (53%)	29	11
NO DATA	126	78	48

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[12] Just over halfway through the data collection, the question of tobacco usage was added to the demographic interview. Smoking is a risk factor for peripheral vascular disease and despite the fact that patients with potential peripheral vascular disease were excluded from the study based on age and history, the potential for smoking being a possible confounder needed to be assessed due to the potential for accelerated atherosclerosis secondary to tobacco usage.

The average age was similar in males and females. There was a black, male preponderance amongst the study participants. Male patients were taller and heavier than the females on average. Due to a higher BMI in females on average, the overall population BMI was on the high side of the normal range. The average arm circumference was virtually the same in both males, females and overall. The average ankle circumference for the study population was 27 cm overall with the female population having a 28 cm average ankle circumference. Most patients presented as a result of a traumatic injury. The vast majority (79%) of the male patients sustained trauma in contrast with only 43% of the female patients. Seventy-five patients were questioned regarding tobacco usage. There were approximately equal numbers of smokers and non-smokers amongst that cohort of patients.

Blood Pressure Measurements

Table 4.2 Average pulse rate, arm and ankle blood pressures

BP measurements are in mmHg

	TOTAL	MALE	FEMALE	P VALUE
AVERAGE PULSE (bpm)	69 (51 – 91)	66 (51 – 85)	77 (57 – 99)	< 0.0001
AVERAGE SBP ARM	123 (105 – 151)	126 (105 – 158)	117 (103 – 134)	< 0.0001
AVERAGE DBP ARM	73 (58 – 94)	74 (58 – 96)	70 (58 – 85)	0.024
AVERAGE MAP ARM	92 (77 – 116)	94 (77 – 121)	88 (75 – 102)	0.0007
AVERAGE SBP ANKLE	137 (113 – 177)	141 (117 – 180)	127 (112 – 146)	< 0.0001
AVERAGE DBP ANKLE	71 (57 – 91)	73 (58 – 94)	67 (57 – 81)	< 0.0001
AVERAGE MAP ANKLE	97 (80 – 122)	100 (81 – 128)	90 (79 – 106)	< 0.0001

The average pulse rate of the study population was 69 bpm with no significant difference between male and female patients. The average arm blood pressure for the overall population was 123/73 mmHg with a MAP of 92 mmHg. There was no statistically or clinically significant difference in the blood pressure measurements between the male and female patients although the BP measured in females was on average 9 mmHg lower than in male patients. The average ankle blood pressure for the overall population was 137/71 mmHg with a MAP of 92 mmHg. There was no statistically significant difference between males and females but there was clinically significant difference of 14 mmHg between the SBP of male and female patients.

Differences in the sequence of BP measurements

Table 4.3 Differences in the sequence of BP measurements

NS Not significant

ORDER	1ST	2ND	3RD	4TH	P VALUE
AVERAGE SBP	131 (91 – 171)	130 (95 – 165)	130 (94 – 166)	129 (92 – 166)	NS
AVERAGE DBP	72 (50 – 94)	72 (50 – 94)	71 (50 – 93)	72 (50 – 94)	NS
AVERAGE MAP	95 (67 – 122)	94 (69 – 120)	94 (68 – 119)	94 (69 – 120)	NS

The order in which the blood pressures were measured did not affect the comparison between the arm and the ankle readings.

Percentage of patients that could use the same cuff for both arm and ankle

Table 4.4 Percentage of patients that could use the same cuff for both arm and ankle

Percentage (actual number); Percentages may not add up to 100% due to rounding

TOTAL 90.6% (182)	SMALL ADULT ARM	ADULT ARM	LARGE ADULT ARM	THIGH CUFF ARM
SMALL ADULT ANKLE	8.0% (16)	7	0	0
ADULT ANKLE	0	71.1% (143)	11	1
LARGE ADULT ANKLE	0	0	11.4% (23)	0
THIGH CUFF ANKLE	0	0	0	0

In almost 91% of the study population, the same cuff could be used for both the patient's arm and ankle. One third of fatter patients and one third of thinner patients had an arm cuff size which differed from their ankle cuff size. This meant that different cuffs were required for their BP measurements on their arm as opposed to their ankle.

Number of patients classified as hypertensive according to the JNC VII criteria [16] by arm versus ankle

Table 4.5 Number of patients classified as hypertensive according to the JNC VII criteria [16] by arm versus ankle
(McNemar test)

	ARM HYPERTENSIVES	ANKLE HYPERTENSIVES	P VALUE
Systolic BP	26	62	< 0.0001
Diastolic BP	14	11	0.54

There was a greater number of patients that would be classified as hypertensive if the ankle SBP was used instead of the arm SBP. There was no difference when using the DBP criteria.

Difference in BP between the left and right arms

Table 4.6 Difference between the left and right arms

(Paired t-test)

	LEFT ARM	RIGHT ARM	P VALUE
AVERAGE SBP	123	124	0.3001
AVERAGE DBP	73	72	0.0016
AVERAGE MAP	92	92	0.1230

As can be seen in Table 4.6, although there was a statistically significant difference in DBP between the left and right arms of 1-2 mmHg, this is not clinically or practically significant. The comparison between the arm and the ankle was therefore done using the average arm versus the average ankle blood pressures.

Difference in BP between the left and right ankles

Table 4.7 Difference between the left and right ankles

(Paired t-test)

	LEFT ANKLE	RIGHT ANKLE	P VALUE
AVERAGE SBP	138	136	0.0115
AVERAGE DBP	72	70	0.0062
AVERAGE MAP	97	96	0.0021

As can be seen in Table 4.7, although there was a statistically significant difference between the left and right ankle of 1-2 mmHg, this is not clinically or practically significant.

Difference between average arm and average ankle SBP

Table 4.8 Difference between average arm and average ankle SBP (Paired t-test)

SEX	AVERAGE SBP ARM	AVERAGE SBP ANKLE	P VALUE
MALE	126	141	P < 0.0001
FEMALE	117	127	P < 0.0001
TOTAL	123	137	P < 0.0001

There is a statistically and clinically significant difference between arm and ankle SBP in males, females and overall.

Difference between average arm and average ankle DBP

Table 4.9 Difference between average arm and average ankle DBP (Paired t-test)

SEX	AVERAGE DBP ARM	AVERAGE DBP ANKLE	P VALUE
MALE	74	73	0.0115
FEMALE	70	67	P < 0.0001
TOTAL	73	71	P < 0.0001

There is a statistically significant difference between arm and ankle DBP in males, females and overall. This difference is not clinically significant.

Difference between average arm and average ankle MAP

Table 4.10 Difference between average arm and average ankle MAP (Paired t-test)

SEX	AVERAGE MAP ARM	AVERAGE MAP ANKLE	P VALUE
MALE	94	100	P < 0.0001
FEMALE	88	90	P < 0.0001
TOTAL	92	97	P < 0.0001

There is a statistically significant difference between arm and ankle MAP in males, females and overall. This difference is not clinically significant.

Average actual, absolute and percentage differences between arm and ankle blood pressures

Table 4.11 Average actual, absolute and percentage differences between arm and ankle blood pressures

	AVERAGE DIFFERENCE ARM ANKLE SBP	AVERAGE DIFFERENCE ARM ANKLE DBP	AVERAGE DIFFERENCE ARM ANKLE MAP
ACTUAL	-13 (-28 to 1)	2 (-7 to 10)	-5 (-13 to 4)
ABSOLUTE	14 (2 to 28)	4 (1 to 11)	6 (1 to 13)
PERCENTAGE	-11 (-22 to 1)	2 (-6 to 8)	-5 (-19 to 6)

The actual, absolute and percentage differences between the arm and ankle SBP were clinically significantly different. The actual, absolute and percentage differences between the arm and ankle DBP were within the clinically acceptable range. The average actual, absolute and percentage differences between the arm and ankle MAP were within the clinically acceptable range, but the range of the CI was not.

Identification of associations between variables and ankle-arm BP difference

Table 4.12 SBP readings according to categories

Average (95% CI); Negative values indicate ankle BP > arm BP

	ACTUAL AVERAGE DIFFERENCE ARM ANKLE	ABSOLUTE AVERAGE DIFFERENCE ARM ANKLE	PERCENTAGE AVERAGE DIFFERENCE ARM ANKLE
SEX			
MALE [138]	-15 (-33 to -1)	15 (2 to 33)	-12 (-24 to 0)
FEMALE [63]	-10 (-22 to 4)	11 (1 to 22)	-9 (-17 to 3)
AGE (years)			
18-30 [77]	-12 (-27 to 2)	12 (1 to 27)	-9 (-22 to 1)
31-40 [64]	-13 (-26 to 0)	14 (4 to 26)	-11 (-19 to 0)
41-50 [60]	-16 (-36 to -2)	16 (4 to 36)	-12 (-26 to -2)
RACE			
BLACK [127]	-14 (-29 to -1)	11 (3 to 29)	-11 (-23 to -1)
COLOURED & INDIAN [23]	-12 (-25 to 1)	12 (2 to 25)	-10 (-22 to 0)
WHITE [51]	-12 (-28 to 3)	12 (1 to 28)	-10 (-21 to 2)
HEIGHT (cm) [200]			
≤160 [33]	-12 (-25 to -1)	12 (1 to 25)	-10 (-22 to 0)
161-180 [138]	-14 (-28 to 1)	14 (4 to 28)	-11 (-23 to 0)
> 180 [29]	-13 (-33 to 3)	14 (2 to 33)	-10 (-22 to 2)
WEIGHT (kg)			
≤ 70 [88]	-14 (-27 to -5)	15 (6 to 27)	-12 (-23 to -4)
71-100 [100]	-13 (-30 to 1)	13 (1 to 30)	-10 (-22 to 0)
> 100 [12]	-11 (-38 to 8)	13 (4 to 38)	-8 (-28 to 6)
BMI (kg/m^2) [200]			
UNDERWEIGHT (≤18) [9]	-12 (-25 to -3)	12 (3 to 25)	-11 (-22 to -2)
NORMAL (19-25) [94]	-14 (-29 to -1)	15 (2 to 29)	-12 (-24 to 0)
OVERWEIGHT (26-30) [64]	-13 (-26 to 1)	13 (2 to 26)	-11 (-20 to 0)
OBESE (31-40) [27]	-12 (-28 to 1)	13 (1 to 28)	-9 (-21 to 0)
MORBIDLY OBESE (>40) [6]	-11 (-38 to 6)	13 (4 to 38)	-8 (-28 to 4)
ARM CUFF SIZE[13]			
SMALL ADULT [16]	-17 (-37 to -6)	17 (6 to 37)	-14 (-27 to -4)
ADULT [150]	-13 (-28 to -1)	14 (2 to 28)	-11 (-21 to 0)
LARGE ADULT [34]	-11 (-31 to 6)	12 (2 to 31)	-9 (-24 to 4)
ANKLE CUFF SIZE			
SMALL ADULT [23]	-17 (-33 to -8)	17 (8 to 33)	-14 (-24 to -6)
ADULT [155]	-14 (-28 to -1)	-11 (-21 to 0)	14 (2 to 28)
LARGE ADULT [23]	-9 (-24 to 6)	11 (2 to 24)	-7 (-17 to 4)

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[13] There was only one data point for a thigh cuff used on the arm.

Table 4.12 SBP readings according to categories (continued)

	ACTUAL AVERAGE DIFFERENCE ARM ANKLE	ABSOLUTE AVERAGE DIFFERENCE ARM ANKLE	PERCENTAGE AVERAGE DIFFERENCE ARM ANKLE
NON-TRAUMA [65]	-14 (-28 to -1)	14 (2 to 28)	-11 (-22 to -1)
SMOKER [35]	-15 (-33 to -2)	16 (3 to 33)	-12 (-24 to -1)
NON-SMOKER [40]	-15 (-34 to 2)	15 (2 to 34)	-12 (-24 to 1)
PULSE (bpm)			
≤ 60 [48]	-15 (-28 to -5)	15 (5 to 28)	-13 (-23 to -4)
60-80 [125]	-14 (-29 to 1)	14 (2 to 29)	-11 (-22 to 1)
> 80 [28]	-8 (-23 to 8)	10 (1 to 23)	-7 (-19 to 6)
ARM SBP RANGE			
≤ 120 mmHg [95]	-12 (-26 to 0)	13 (2 to 26)	-11 (-23 to 0)
121-150 mmHg [95]	-13 (-30 to 2)	14 (1 to 31)	-10 (-22 to 1)
> 150 mmHg [11]	-24 (-38 to -9)	24 (9 to 38)	-15 (-22 to -5)
ARM DBP RANGE			
< 70 mmHg [91]	-11 (-23 to 2)	11 (1 to 23)	-10 (-20 to 1)
71-90 mmHg [96]	-14 (-33 to -1)	15 (4 to 33)	-11 (-25 to 0)
> 90 mmHg [14]	-22 (-38 to -9)	22 (9 to 38)	-14 (-21 to -5)
ARM MAP RANGE			
≤ 86 mmHg [76]	-11 (-26 to 2)	11 (1 to 26)	-10 (-23 to 1)
87-110 mmHg [107]	-14 (-29 to -1)	14 (3 to 29)	-11 (-23 to 0)
≥ 111 mmHg [18]	-23 (-38 to -9)	23 (9 to 38)	-15 (-22 to -5)

Table 4.12 displays the actual, absolute and percentage average difference between arm and ankle SBP in order to assess whether there was any effect from the following variables: sex, age, race, height, weight, BMI, arm cuff size, ankle cuff size, reason for presentation, tobacco usage, pulse, arm SBP range, arm DBP range and arm MAP range.

Table 4.13 DBP readings according to categories

Average (95% CI); Negative values indicate ankle BP > arm BP

	ACTUAL AVERAGE DIFFERENCE ARM ANKLE	ABSOLUTE AVERAGE DIFFERENCE ARM ANKLE	PERCENTAGE AVERAGE DIFFERENCE ARM ANKLE
SEX			
MALE [138]	1 (-8 to 8)	4 (1 to 9)	1 (-6 to 6)
FEMALE [63]	3 (-7 to 15)	5 (1 to 15)	3 (-6 to 12)
AGE (years)			
18-30 [77]	1 (-8 to 10)	4 (1 to 10)	1 (-6 to 8)
31-40 [64]	2 (-7 to 9)	4 (1 to 10)	2 (-6 to 7)
41-50 [60]	2 (6 to 12)	4 (0 to 13)	2 (-5 to 9)
RACE			
BLACK [127]	1 (-8 to 10)	4 (1 to 12)	1 (-6 to 8)
COLOURED & INDIAN [23]	3 (-3 to 9)	4 (0 to 9)	3 (-2 to 8)
WHITE [51]	2 (-6 to 10)	4 (0 to 10)	2 (-5 to 9)
HEIGHT (cm)			
≤160 [33]	3 (-7 to 15)	5 (1 to 15)	2 (-6 to 12)
161-180 [138]	2 (-8 to 10)	4 (1 to 11)	1 (-6 to 8)
> 180 [29]	1 (-6 to 8)	4 (0 to 9)	1 (-5 to 6)
WEIGHT (kg)			
≤ 70 [88]	1 (-6 to 8)	4 (1 to 9)	1 (-5 to 7)
71-100 [100]	2 (-7 to 10)	5 (1 to 10)	2 (-6 to 8)
> 100 [12]	2 (-18 to 17)	6 (0 to 18)	2 (-15 to 13)
BMI (kg/m^2) [200]			
UNDERWEIGHT (≤18) [9]	3 (-6 to 9)	4 (1 to 9)	2 (-5 to 8)
NORMAL (19-25) [94]	1 (-8 to 9)	4 (1 to 10)	1 (-7 to 9)
OVERWEIGHT (26-30) [64]	2 (-6 to 9)	4 (1 to 9)	2 (-4 to 7)
OBESE (31-40) [27]	4 (-7 to 16)	6 (0 to 16)	3 (-6 to 13)
MORBIDLY OBESE (>40) [6]	-1 (-18 to 15)	7 (1 to 18)	-1 (-15 to 12)
ARM CUFF SIZE[14]			
SMALL ADULT [16]	1 (-8 to 9)	4 (1 to 9)	1 (-6 to 8)
ADULT [150]	2 (-6 to 10)	4 (0 to 10)	2 (-5 to 8)
LARGE ADULT [34]	2 (-8 to 16)	5 (0 to 16)	2 (-6 to 13)
ANKLE CUFF SIZE			
SMALL ADULT [23]	1 (-6 to 8)	3 (1 to 8)	1 (-5 to 7)
ADULT [155]	2 (-8 to 10)	4 (1 to 11)	1 (-6 to 8)
LARGE ADULT [23]	4 (-5 to 16)	5 (1 to 16)	3 (-3 to 13)

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[14] There was only one data point for a thigh cuff used on the arm.

Table 4.13 DBP readings according to categories (continued)

	ACTUAL AVERAGE DIFFERENCE ARM ANKLE	ABSOLUTE AVERAGE DIFFERENCE ARM ANKLE	PERCENTAGE AVERAGE DIFFERENCE ARM ANKLE
TRAUMA [136]	2 (-6 to 10)	4 (1 to 10)	1 (-5 to 8)
NON-TRAUMA [65]	2 (-7 to 10)	4 (1 to 11)	2 (-6 to 9)
SMOKER [35]	2 (-8 to 8)	4 (0 to 12)	1 (-6 to 6)
NON-SMOKER [40]	2 (-4 to 11)	4 (1 to 11)	1 (-4 to 8)
PULSE (bpm)			
≤ 60 [48]	2 (-7 to 9)	4 (1 to 9)	1 (-6 to 8)
60-80 [125]	2 (-7 to 9)	4 (1 to 10)	1 (-6 to 8)
> 80 [28]	3 (-6 to 16)	5 (0 to 17)	3 (-5 to 13)
ARM SBP RANGE			
≤ 120 mmHg [95]	1 (-8 to 9)	4 (1 to 9)	1 (-6 to 8)
121-150 mmHg [95]	2 (-5 to 12)	4 (1 to 12)	2 (-4 to 9)
> 150 mmHg [11]	2 (-12 to 12)	5 (0 to 12)	1 (-7 to 7)
ARM DBP RANGE			
< 70 mmHg [91]	0 (-8 to 9)	4 (1 to 9)	0 (-6 to 7)
71-90 mmHg [96]	3 (-5 to 12)	4 (0 to 12)	2 (-4 to 9)
> 90 mmHg [14]	4 (-12 to 12)	6 (2 to 12)	2 (-7 to 9)
ARM MAP RANGE			
≤ 86 mmHg [76]	0 (-8 to 9)	4 (2 to 10)	0 (-6 to 8)
87-110 mmHg [107]	3 (-5 to 10)	4 (0 to 11)	2 (-4 to 8)
≥ 111 mmHg [18]	3 (-12 to 12)	5 (0 to 12)	2 (-7 to 9)

Table 4.13 displays the actual, absolute and percentage average difference between arm and ankle DBP in order to assess whether there was any effect from the following variables: sex, age, race, height, weight, BMI, arm cuff size, ankle cuff size, reason for presentation, tobacco usage, pulse, arm SBP range, arm DBP range and arm MAP range.

Table 4.14 MAP readings according to categories

Average (95% CI); Negative values indicate ankle BP > arm BP

	ACTUAL AVERAGE DIFFERENCE ARM ANKLE	ABSOLUTE AVERAGE DIFFERENCE ARM ANKLE	PERCENTAGE AVERAGE DIFFERENCE ARM ANKLE
SEX			
MALE [138]	-6 (-14 to 2)	6 (1 to 14)	-8 (-20 to 3)
FEMALE [63]	-3 (-12 to 7)	5 (1 to 12)	-4 (-18 to 10)
AGE (years)			
18-30 [77]	-4 (-13 to 5)	6 (1 to 13)	-7 (-20 to 8)
31-40 [64]	-4 (-13 to 2)	5 (2 to 13)	-6 (-18 to 3)
41-50 [60]	-5 (-14 to 4)	6 (1 to 14)	-7 (-20 to 4)
RACE			
BLACK [127]	-5 (-14 to 3)	6 (1 to 14)	-8 (-20 to 3)
COLOURED & INDIAN [23]	-4 (-11 to 5)	5 (1 to 11)	-5 (-15 to 8)
WHITE [51]	-3 (-12 to 4)	5 (1 to 12)	-5 (-15 to 6)
HEIGHT (cm)			
≤160 [33]	-4 (-12 to 5)	5 (1 to 12)	-5 (-18 to 8)
161-180 [138]	-5 (-14 to 4)	6 (1 to 14)	-7 (-20 to 6)
> 180 [29]	-5 (-14 to 2)	5 (1 to 14)	-6 (-19 to 3)
WEIGHT (kg)			
≤ 70 [88]	-6 (-13 to 2)	6 (1 to 13)	
71-100 [100]	-4 (-12 to 4)	5 (1 to 12)	-6 (-19 to 6)
> 100 [12]	-3 (-17 to 11)	6 (1 to 17)	-4 (-24 to 14)
BMI (kg/m^2) [200]			
UNDERWEIGHT (≤18) [9]	-4 (-12 to 2)	5 (0 to 12)	-6 (-15 to 2)
NORMAL (19-25) [94]	-6 (-14 to 4)	7 (1 to 14)	-8 (-20 to 6)
OVERWEIGHT (26-30) [64]	-4 (-12 to 1)	5 (1 to 12)	-6 (-14 to 1)
OBESE (31-40) [27]	-3 (-12 to 7)	5 (1 to 12)	-4 (-18 to 10)
MORBIDLY OBESE (>40) [6]	-5 (-17 to 10)	8 (2 to 17)	-8 (-24 to 14)
ARM CUFF SIZE[15]			
SMALL ADULT [16]	-7 (-17 to 1)	8 (0 to 17)	-11 (-27 to 2)
ADULT [150]	-5 (-12 to 3)	5 (1 to 12)	-6 (-17 to 3)
LARGE ADULT [34]	-3 (-17 to 10)	5 (1 to 17)	-5 (-21 to 13)
ANKLE CUFF SIZE			
SMALL ADULT [23]	-7 (-14 to 0)	-10 (-20 to 0)	7 (0 to 14)
ADULT [155]	-5 (-13 to 3)	6 (1 to 13)	-7 (-19 to 3)
LARGE ADULT [23]	-2 (-10 to 10)	5 (1 to 11)	-2 (-15 to 13)

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[15] There was only one data point for a thigh cuff used on the arm.

Table 4.14 MAP readings according to categories (continued)

	ACTUAL AVERAGE DIFFERENCE ARM ANKLE	ABSOLUTE AVERAGE DIFFERENCE ARM ANKLE	PERCENTAGE AVERAGE DIFFERENCE ARM ANKLE
TRAUMA [136]	-5 (-14 to 5)	6 (1 to 14)	-7 (-20 to 7)
NON-TRAUMA [65]	-5 (-12 to 2)	5 (1 to 12)	-7 (-18 to 3)
SMOKER [35]	-5 (-17 to 3)	6 (1 to 17)	-7 (-23 to 3)
NON-SMOKER [40]	-5 (-13 to 4)	6 (1 to 13)	-7 (-17 to 5)
PULSE (bpm)			
≤ 60 [48]	-6 (-14 to 1)	6 (1 to 14)	-8 (-20 to 1)
60-80 [125]	-5 (-13 to 2)	6 (1 to 13)	-7 (-18 to 3)
> 80 [28]	-2 (-14 to 8)	5 (1 to 14)	-3 (-21 to 10)
ARM SBP RANGE			
≤ 120 mmHg [95]	-5 (-14 to 2)	6 (1 to 14)	-7 (-20 to 3)
121-150 mmHg [95]	-4 (-13 to 6)	5 (1 to 13)	-6 (-17 to 8)
> 150 mmHg [11]	-8 (-22 to 3)	8 (1 to 22)	-8 (-23 to 2)
ARM DBP RANGE			
< 70 mmHg [91]	-5 (-13 to 4)	6 (1 to 13)	-8 (-20 to 6)
71-90 mmHg [96]	-4 (-14 to 5)	5 (1 to 14)	-5 (-17 to 7)
> 90 mmHg [14]	-6 (-22 to 3)	7 (1 to 22)	-7 (-22 to 2)
ARM MAP RANGE			
≤ 86 mmHg [76]	-5 (-14 to 4)	6 (1 to 14)	-8 (-22 to 6)
87-110 mmHg [107]	-4 (-13 to 5)	5 (1 to 13)	-6 (-16 to 7)
≥ 111 mmHg [18]	-6 (-22 to 3)	7 (1 to 22)	-7 (-23 to 2)

Table 4.14 displays the actual, absolute and percentage average difference between arm and ankle MAP in order to assess whether there was any effect from the following variables: sex, age, race, height, weight, BMI, arm cuff size, ankle cuff size, reason for presentation, tobacco usage, pulse, arm SBP range, arm DBP range and arm MAP range.

Regression formula

Using linear regression to identify significant correlations between arm SBP and other variables, the following were found to be linked to the SBP value:-

Arm circumference (0.306)

Weight (-0.15)

Ankle SBP (0.887)

Use of these 3 variables led to an r value of 0.91 and r^2 variance value of 0.83.

This gives the formula:

$$Arm\ SBP = 10 + 0.306\ (arm\ circumference) - 0.15\ (weight) + \ 0.887\ (ankle\ SBP)$$

Equation 4.1 Regression formula equation for the calculation of arm SBP

Using linear regression to identify significant correlations between arm DBP and other variables, the following were found to be linked to the DBP value:-

Height (-0.06)

Ankle DBP (0.89)

Ankle circumference (0.059)

Use of these 3 variables led to an r value of 0.89 and r^2 variance value of 0.79.

This gives the formula:

$$Arm\ DBP = 14 + 0.059\ (ankle\ circumference) - 0.06\ (height) + 0.89\ (ankle\ DBP)$$

Equation 4.2 Regression formula equation for the calculation of arm DBP

Using linear regression to identify significant correlations between arm MAP and other variables, the following were found to be linked to the MAP value:-

Arm circumference (0.077)

Pulse (0.064)

Ankle MAP (0.918)

Use of these 3 variables led to an r value of 0.93 and r^2 variance value of 0.87.

This gives the formula:

$$Arm\ MAP = 1.5 + 0.077(arm\ circumference) + 0.064(pulse) + 0.918(ankle\ MAP)$$

Equation 4.3 Regression formula equation for the calculation of arm MAP

Correlation analysis

Table 4.15 Table of correlations

Red numbers indicate significant correlations

	Age	Height	Weight	BMI	Pulse	Arm circ	Ankle circ	Diff SBP	Diff DBP	Diff MAP	Arm SBP	Arm DBP	Arm MAP	Ankle SBP	Ankle DBP	Ankle MAP
Age	1.000000															
Height	-0.133540	1.000000														
Weight	0.233594	0.334582	1.000000													
BMI	0.324418	-0.172575	0.864719	1.000000												
Pulse	0.096291	-0.221813	0.135772	0.247112	1.000000											
Arm circ	0.197454	0.122238	0.892695	0.864928	0.171975	1.000000										
Ankle circ	0.165034	0.036351	0.766266	0.777328	0.119480	0.763630	1.000000									
Diff SBP	-0.167129	-0.113524	0.047324	0.114721	0.177972	0.182768	0.102038	1.000000								
Diff DBP	0.072812	-0.148933	0.013255	0.076559	0.169754	0.000248	0.110259	0.224954	1.000000							
Diff MAP	-0.061142	-0.125634	0.088181	0.152906	0.216314	0.154965	0.168955	0.771037	0.740439	1.000000						
Arm SBP	0.136372	0.255029	0.304754	0.176608	-0.043852	0.284572	0.247306	-0.284062	0.057940	-0.087329	1.000000					
Arm DBP	0.313394	0.076136	0.134359	0.094340	0.057747	0.076133	0.113183	-0.401196	0.313081	-0.034850	0.794602	1.000000				
Arm MAP	0.246543	0.164612	0.236360	0.153549	0.008169	0.190126	0.192012	-0.367572	0.193555	-0.056771	0.939799	0.948369	1.000000			
Ankle SBP	0.181795	0.247348	0.210414	0.081309	-0.116276	0.131985	0.141134	-0.682064	-0.060504	-0.425452	0.894916	0.792771	0.887866	1.000000		
Ankle DBP	0.289607	0.152235	0.132987	0.060330	-0.023459	0.078924	0.063334	-0.527090	-0.166329	-0.400029	0.796538	0.884422	0.889550	0.852840	1.000000	
Ankle MAP	0.245586	0.196879	0.178487	0.078852	-0.076577	0.110969	0.107239	-0.629933	-0.113103	-0.439078	0.879608	0.866959	0.921927	0.964062	0.955713	1.000000

The correlation between the arm SBP, DBP and MAP with the ankle SBP, DBP and MAP varied considerably with r^2 values for SBP 0.79, DBP 0.77 and MAP 0.85. Correlation was generally best with MAP and least impressive with DBP.

There was good correlation between the arm MAP with arm SBP (r^2 0.88) and DBP (r^2 0.90) as well as the ankle MAP with ankle SBP (r^2 0.92) and DBP (r^2 0.92).

Arm circumference tended to correlate better with weight (r^2 0.79) and BMI (r^2 0.76) than ankle circumference (weight r^2 0.59 and BMI r^2 0.61). Figures 4.1, 4.2 and 4.3 show the correlation between arm and ankle SBP, DBP and MAP respectively

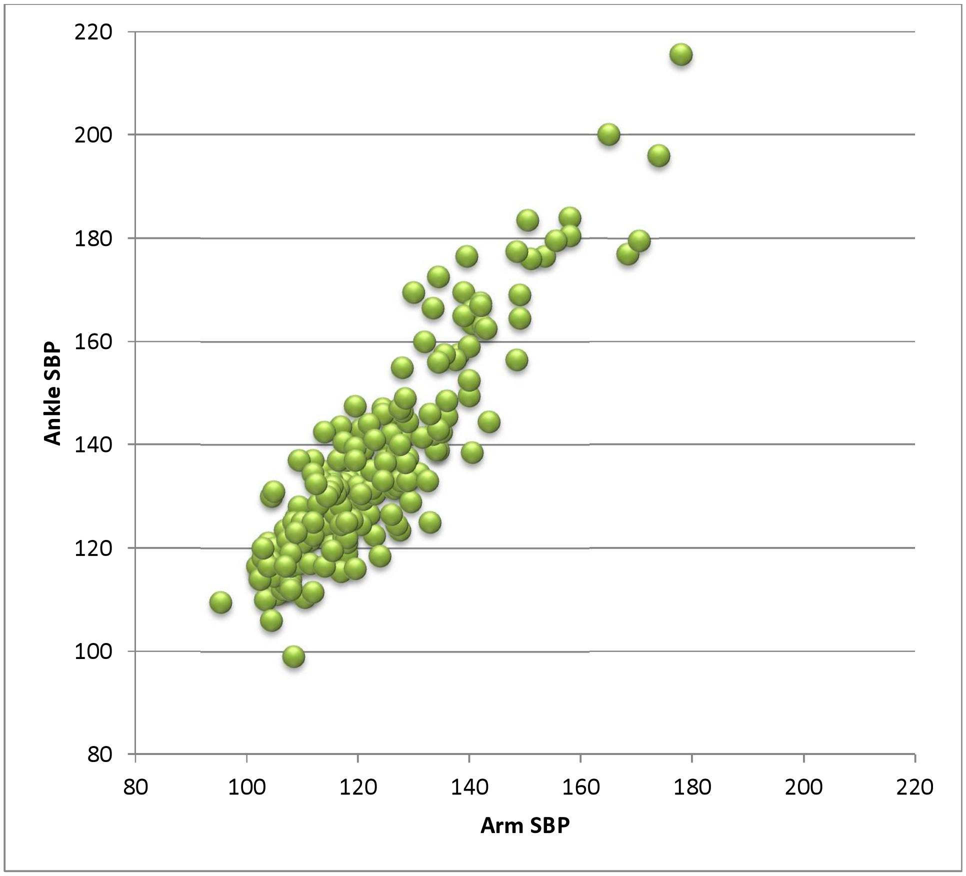


Figure 4.1 Correlation between arm and ankle SBP

(r = 0.89, r2 = 0.79)

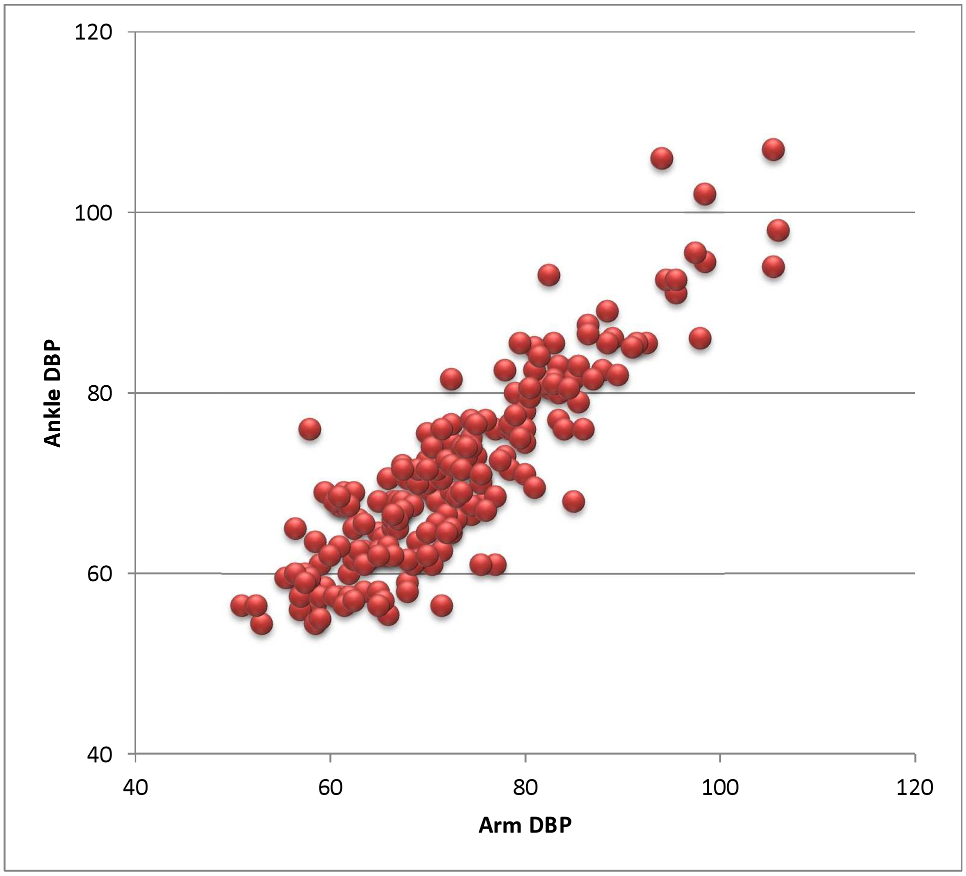


Figure 4.2 Correlation between arm and ankle DBP

(r = 0.88, r^2 = 0.77)

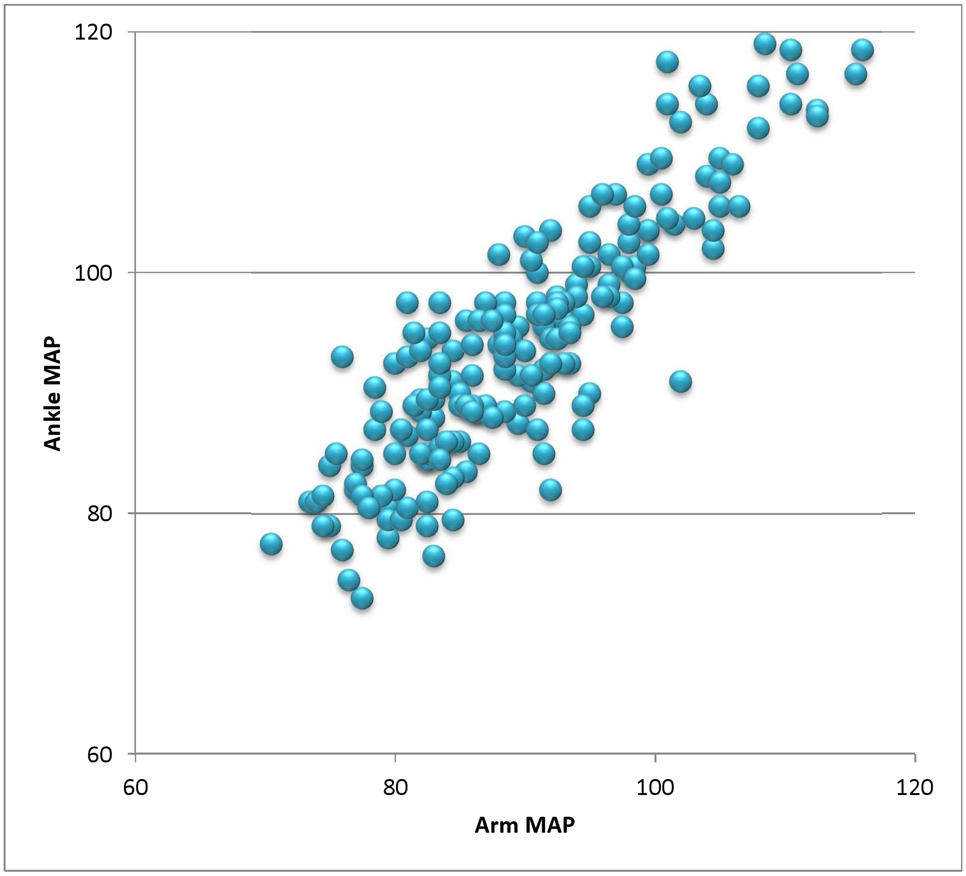


Figure 4.3 Correlation between arm and ankle MAP

(r = 0.92, r^2 = 0.85)

Bland and Altman analysis

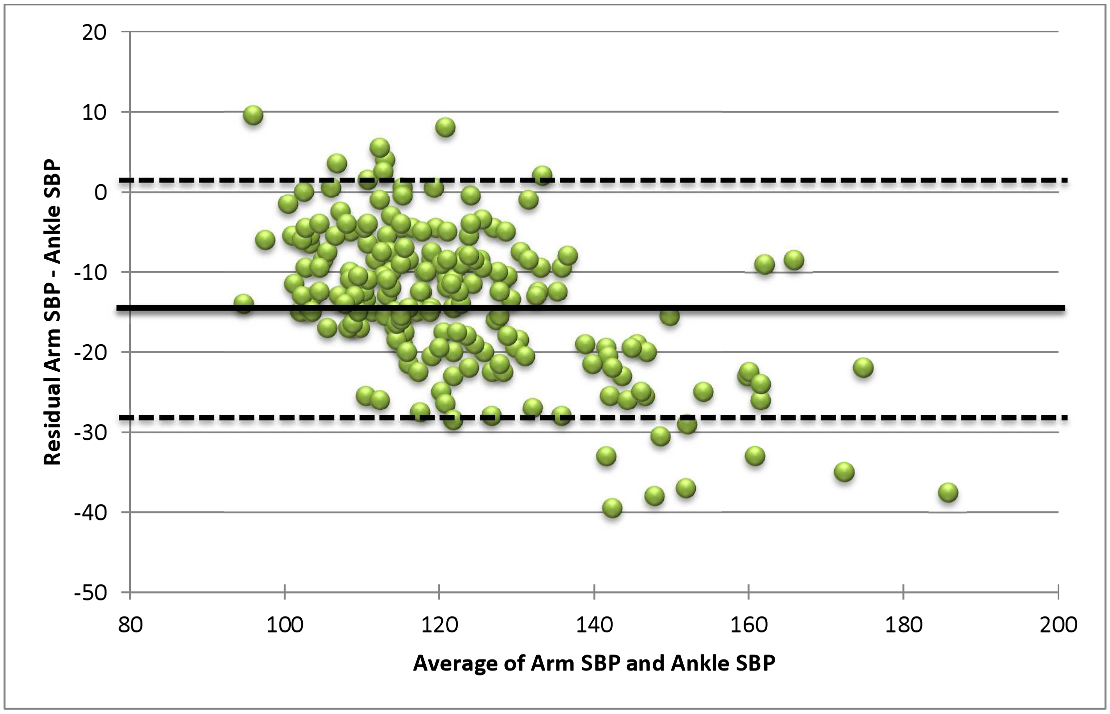


Figure 4.4 Bland-Altman analysis for SBP

(average error = -13, limits of agreement -28 to 1)

The Bland-Altman analysis for SBP showed an average error of -13 mmHg with wide limits of agreement.

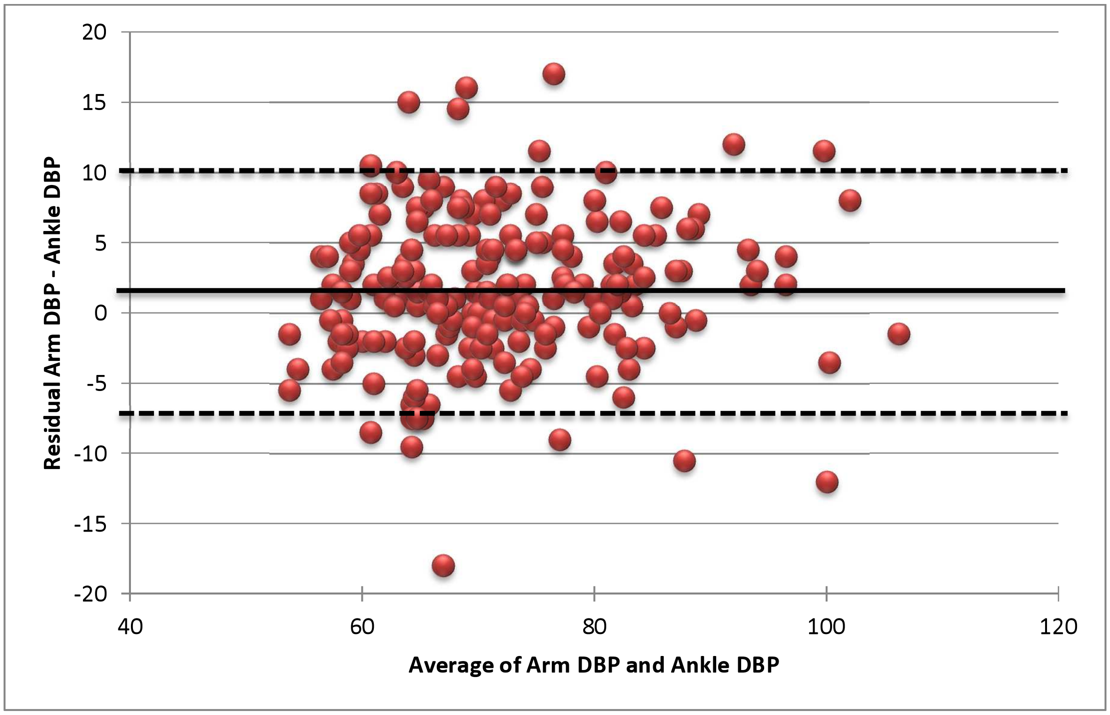


Figure 4.5 Bland-Altman analysis for DBP

(average error = 2, limits of agreement -7 to 10)

Bland-Altman analysis for DBP showed an average error of 2 with narrow limits of agreement. The average error as well as the limits of agreement were within the clinically acceptable difference range.

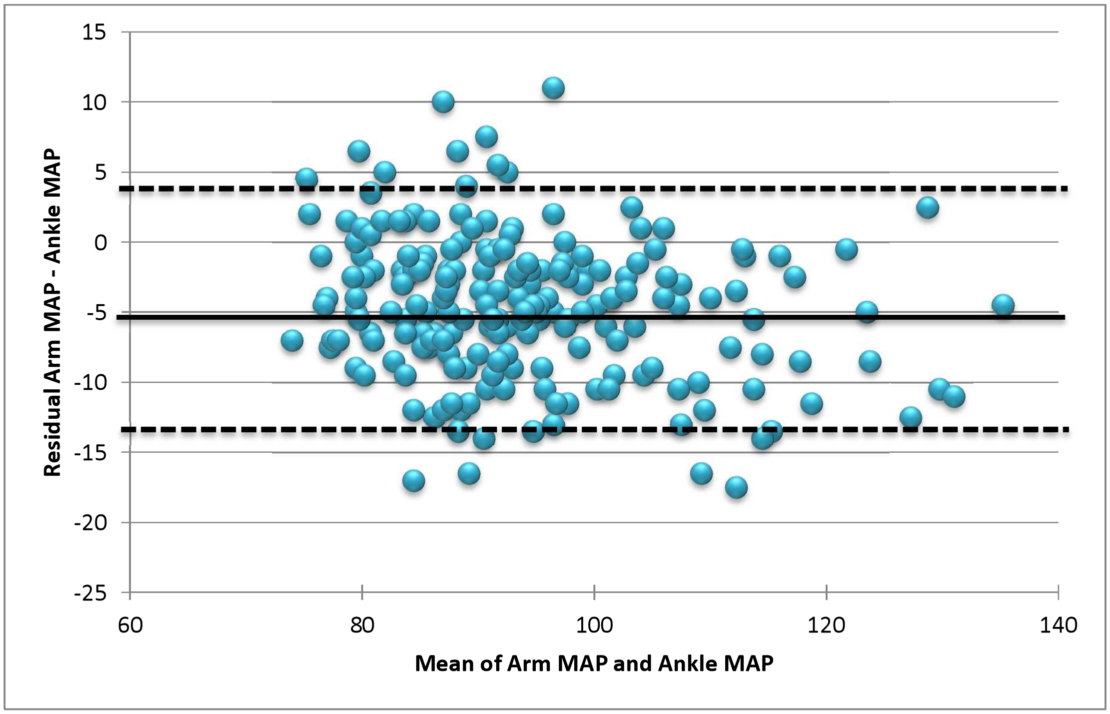


Figure 4.6 Bland-Altman analysis of MAP

(average error = -5, limits of agreement -13 to 4)

When the MAP values were assessed via Bland-Altman analysis, the average error was found to be 5 mmHg higher in the ankle which is clinically acceptable. The limits of agreement extend beyond the clinically acceptable range.

Non-parametric analysis performance

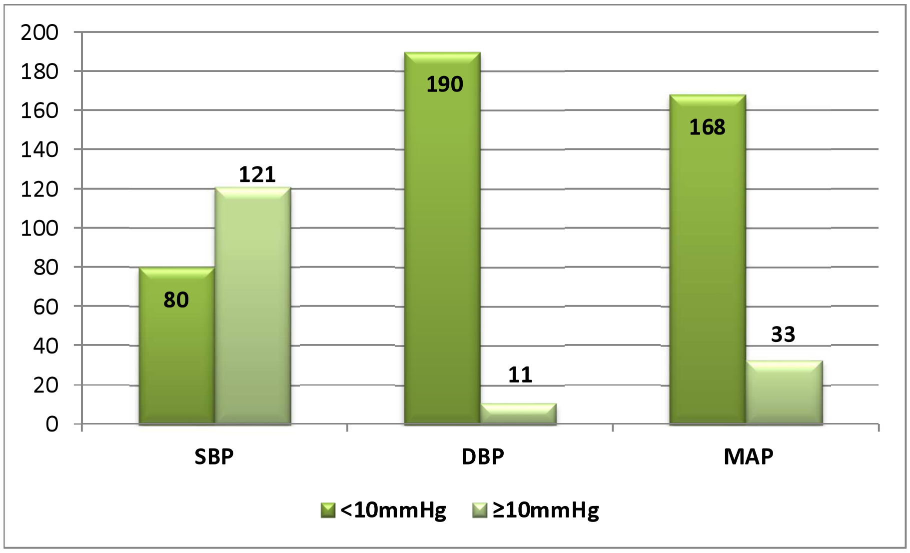


Figure 4.7 Analysis of errors by category

Errors of less than 10 mmHg difference (clinically acceptable) and greater than 10 mmHg difference (clinically not acceptable)

Sixty percent of SBP readings at the ankle were within the clinically acceptable range. The majority (95%) of DBP readings were within the clinically acceptable range. The MAP was in the clinically acceptable range 84% of the time.

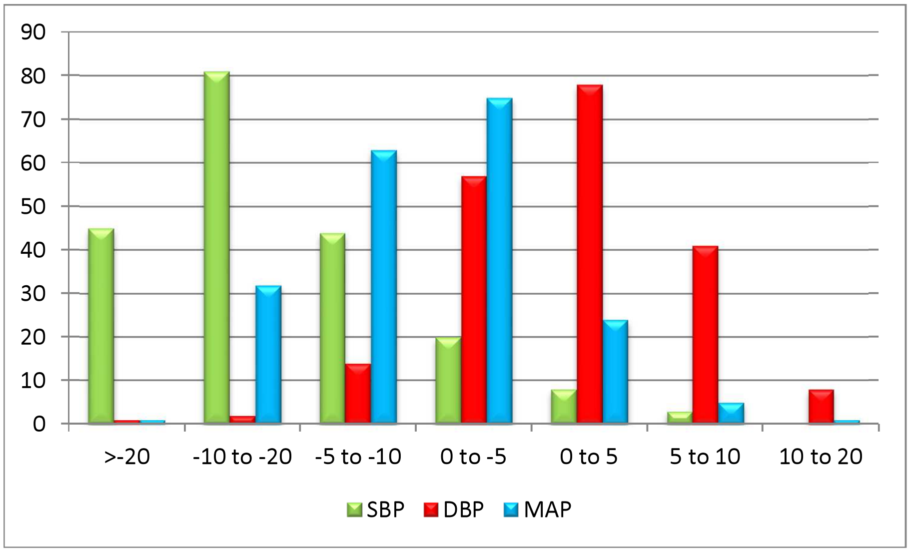


Figure 4.8 Analysis of the actual differences in SBP, DBP and MAP between the average arm and the average ankle measurements

In general, the ankle SBP readings were higher in the ankle than in the arm. The majority of ankle DBP readings were within 10 mmHg of the arm reading and also higher than the arm DBP on average. Most of the ankle MAP readings were also within 10 mmHg of the arm reading with a trend towards being higher than the arm MAP on average.

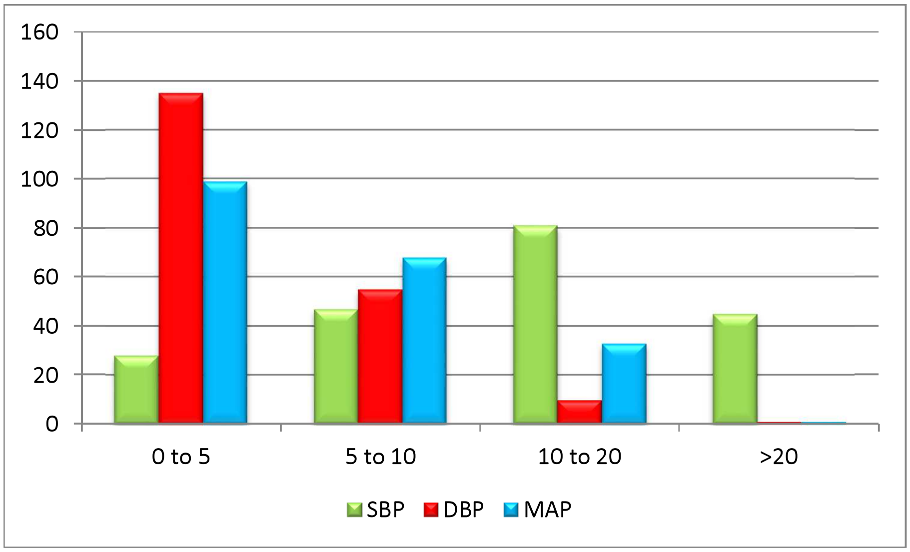


Figure 4.9 Analysis of the absolute differences in SBP, DBP and MAP between the average arm and the average ankle measurements

Figure 4.9 reinforces the trends seen in Figures 4.7 and 4.8. The majority of DBP and MAP readings in the ankle are within ± 10 mmHg of the arm readings. SBP ankle readings are by and large less accurate with differences being greater than 10 mmHg.

Development of a correction factor “Rule-of-thumb” for SBP and MAP

Based on the actual average differences between the arm and the ankle SBP and MAP, a simple rule-of-thumb correction factor was tested to see whether it could improve the accuracy of the ankle SBP and MAP.

A round number was chosen for SBP in order to make it easier to use and remember i.e. 15 mmHg was used instead of the actual average difference of 13 mmHg. The actual average difference of 5 mmHg was applied and used for the MAP correction factor.

$$Estimated\ Arm\ SBP = Ankle\ SBP - 15\ mmHg$$

Equation 4.4 Equation for estimated arm SBP using a correction factor

$$Estimated\ Arm\ MAP = Ankle\ MAP - 5\ mmHg$$

Equation 4.5 Equation for estimated arm MAP using a correction factor

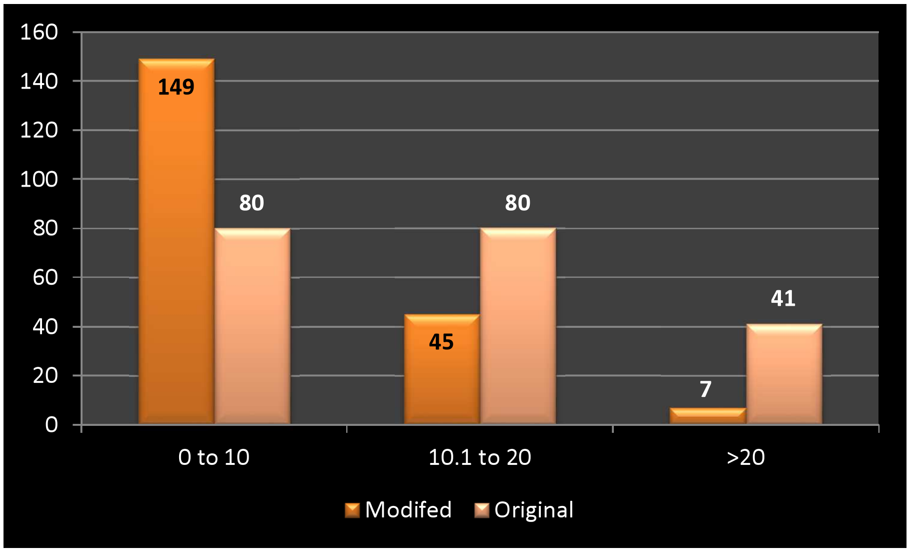


Figure 4.10 SBP absolute differences after modification by a correction factor

The application of a correction factor to the measured ankle SBP improved the accuracy in the prediction of the arm SBP significantly. The average difference between arm and ankle SBP fell from -13 mmHg to 2 mmHg and the average absolute difference fell from 14 mmHg to 7 mmHg ($p<0.0001$). Ankle SBP was different from arm SBP within the clinically acceptable range of 10 mmHg in 74% of patients compared to the original figure of 40% ($p<0.0001$).

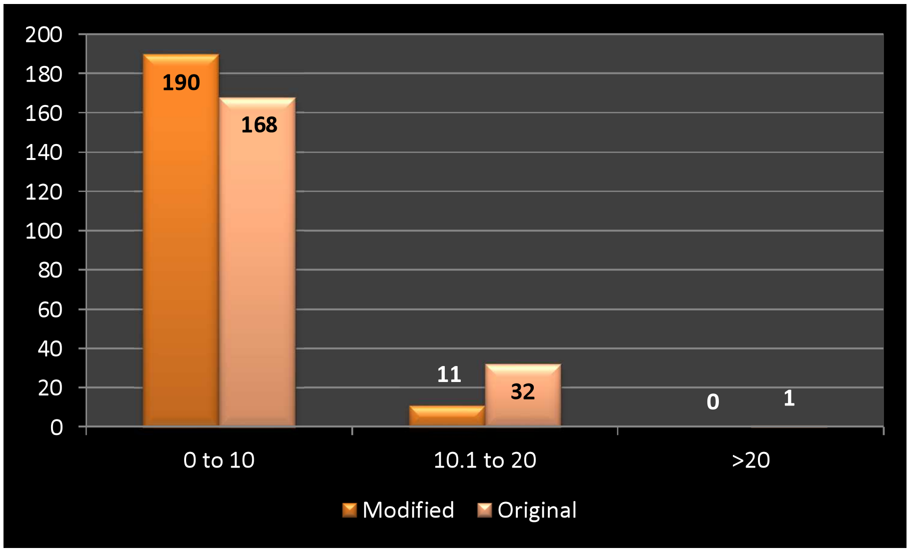


Figure 4.11 MAP absolute differences after modification by a correction factor

The application of a correction factor to the measured ankle MAP improved the accuracy in the prediction of the arm MAP significantly. The average difference between arm and ankle MAP fell from -5 mmHg to 0 mmHg and the average absolute difference fell from 6 mmHg to 4mmHg ($p<0.0001$). The number of ankle MAP readings that then fall within the clinically acceptable range of 10 mmHg from the arm MAP is 95% of patients compared to the original figure of 84% ($p=0.0004$).

Chapter 5 DISCUSSION

This discussion will initially be focused on the results obtained in the study followed an analysis of the relevance thereof.

Basic Demographic Data

The demographics of this study population are typically representative of the average ED demographics in South Africa with the exception of paediatric and geriatric patients who were excluded from the study. There is a male preponderance which is expected based on the higher incidence of trauma-related presenting complaints. The mix of racial groups is fairly typical and in keeping with the demographics of the drainage area of the hospital. The commonly referred to "average male patient weighing 75 kg" was found, with the average female patient weighing 72 kg.

The average BMI of the patient population falls into the overweight category (26 – 30 kg/m^2). This is as a result of the female portion of the population having an average BMI of 27.8 kg/m^2. This is in keeping with the Glaxo-Smith Kline survey released in November 2011 which showed that South Africa is the 3rd fattest country in the world behind the United States of America and Great Britain [116]. The bulk of the male patients were "young, fit, healthy males" which helped to keep the BMI for the male category within normal limits.

The arm and ankle circumferences were fairly similar. Between the sexes, females had a slightly larger confidence interval probably related to their overall higher

BMI. The higher weight for height ratio amongst the females is associated with excess adipose deposition on their arms.

Trauma was the most common reason for presentation to the ED amongst the study population with injuries sustained on duty at work being the commonest cause.

Just over halfway through the data collection, the question of tobacco usage was added to the demographic interview. Smoking is a risk factor for peripheral vascular disease [59], and despite the fact that patients with potential peripheral vascular disease were excluded from the study based on age and history, the potential for smoking being a possible confounder needed to be assessed due to the potential for accelerated atherosclerosis secondary to tobacco usage. Smoking also increases BP in the acute phase of use owing to the stimulant nature of the nicotine in tobacco products. Thirty-seven percent of the total population were questioned with an almost equal distribution of smokers and non-smokers.

Blood pressure measurements

The average pulse rate for both males and females fell within the normal range. Male patients had a statistically significantly lower pulse than females most likely related to the fact that they were healthy and fit related to their physically-demanding work.

The average blood pressure measurement for the study population was 123/73 mmHg with a MAP of 92 mmHg. The average female SBP, DBP and MAP was significantly lower than the average male SBP, DBP and MAP. This was also mirrored in the average ankle SBP, DBP and MAP in males and females. Blood pressure measurements in females are usually lower than in males [117]. The population in general thus had a normal blood pressure on average. The average blood pressure measurements were normal in both males and females.

The average ankle SBP was 14 mmHg higher than the average arm SBP which is both statistically and clinically significant (Tables 4.2 and 4.8). The average arm and ankle DBP only differ by 2 mmHg and the average arm and ankle MAP only differ by 5 mmHg – neither of which are clinically significant. It is interesting to note that despite the fact that the MAP is the pressure that is being measured by the NIBP machine, it is the calculated DBP that on average has the least difference between the arm and the ankle.

Differences in the sequence of BP measurement

Analysis of the order of the BP measurement showed that there was no statistically significant effect on the blood pressures obtained attributable to the order in which they were measured. Braam and Thien as well as Chang *et al.* found that sequential blood pressure measurements could lead to inaccuracy but the order of taking the blood pressure did not have any effect on the measurements in this study and therefore is not considered to be a confounder [99, 115].

Percentage of patients that could use the same cuff for both arm and ankle

The same cuff could be used on both the arm and the ankle in 91% of the patient population. This is useful in the ED from a practical point of view as it allows the BP cuff to be easily interchanged between the arm and the ankle. The commonest alternate cuff required was a "large adult" cuff for the arm when a standard adult cuff could be used on the ankle. Seventy one percent of patients could use the "adult" cuff on both the arm and the ankle. The study population does demonstrate that 17% of patients did require a "large adult" cuff in order to measure their blood pressure at the arm. This cuff should therefore be readily available in the ED should the need arise.

Number of patients classified as hypertensive according to the JNC VII criteria [16] by arm versus ankle

Similar to the findings by Jones *et al.* regarding the misclassification of patients as hypertensive, 2.4 times as many patients would have been misclassified as being hypertensive based on the ankle SBP instead of the arm SBP [28]. Diagnosis based on DBP did not show a similar pattern with the difference in the number of arm DBP diagnosed hypertensives compared to ankle DBP diagnosed hypertensives not being statistically significant. This is likely to be related to the average arm DBP and ankle DBP only differing by 2 mmHg.

Difference between the left and right arms

There was no statistically significant difference in SBP or MAP between the left and right arms. Although there was a statistically significant difference in the left and right arm DBP the actual difference of 72 vs 73 mmHg together with narrow CI is not significant in practice. Statistical significance was probably due to similar narrow variance amongst the DBP readings between the arm and ankle.

Difference between the left and right ankles

The average BP readings in the left and right ankles showed a statistically significant difference between them, but again, this was not practically relevant with differences of 1 to 2 mmHg.

Difference between average arm and average ankle pressures

As can be seen from the above, although there is a statistically significant difference between the left and right side of the body of 1 to 2 mmHg, this is not clinically or practically significant. Hence the comparison between the arm and the ankle were done on the average arm versus the average ankle blood pressures.

The SBP in the arms and ankles of both males and females differed statistically as well as clinically significantly. The SBP measured in the ankle of the male patients was 15 mmHg higher on average and 10 mmHg higher on average in females. The overall increase in the ankle SBP compared to the arm was 14 mmHg.

Although the DBP differences between the arm and the ankle in both sexes and overall were statistically significant, they were not clinically significant with the difference being only 1 to 3 mmHg. The ankle DBP were lower than the measured arm DBP as the measurement is being done in more distal vessels.

The MAP in both sexes and overall was also statistically significantly different between the arm and the ankle with higher pressure noted in the ankle, but the figures did not reach clinical significance.

Average actual, absolute and percentage differences between arm and ankle blood pressures

The average actual difference in BP refers to the bias of the ankle BPs when compared to the arm BPs. This is the average difference between the arm and the ankle blood pressures whether the measured ankle BP is higher or lower than the measured arm BP. The absolute average difference in BP refers to the precision of the data. It reflects the difference between the arm and the ankle as an absolute value i.e. does not take into consideration whether the BP is higher or lower than the arm but rather just the amount of deviation from the arm BP.

The average actual difference between the SBP in the arm and the ankle is -13 mmHg i.e. the SBP measured in the ankle will be 13 mmHg higher than that measured in the arm. This in itself is not clinically acceptable but what is more unfortunate is that this measurement is not constant amongst different patients. The ankle SBP can be up to 28 mmHg higher but conversely 1 mmHg lower than the measured SBP in the arm (95% CI). This shows that the bias of the measurement is, in general, prone to overestimation but by varying degrees. The wide confidence intervals also demonstrate that the average difference that may apply to the patient population but cannot be used in order to estimate the SBP in the individual. This statistically and clinically significant absolute difference in SBP translates to a mean percentage difference of 11% which again is unacceptable and cannot be applied to the individual patient. The wide confidence interval implies that a simple correction factor is also not likely to improve on this difference.

Surprisingly, DBP fared the best with absolute and actual differences between the arm and the ankle being 4 and 2 mmHg respectively. This shows minimal bias and reasonable precision of the DBP ankle measurement compared to the arm with an ankle reading that is on average only 2% higher than the measured arm DBP. The reason it is surprising is based on the function of the oscillatory BP machine. The machine measures the MAP and calculates the SBP and DBP. Therefore a measured value should technically be more precise, but this is not the case. The CI for the absolute average DBP extends beyond the clinically significant range of 10 mmHg though, and with the actual CI range being from -7 to 10 mmHg, this could mean a measured DBP at the ankle could be 7 mmHg lower or up to 10 mmHg higher than the arm. Albeit within the “clinically acceptable” range, the fact that the measured DBP can be higher or lower than the true arm DBP might pose a problem when making a decision based on that measured DBP. A caveat to the DBP being the most precise and prone to the least amount of over- or underestimation is that DBP is not usually the value that clinical decisions are based on in a medical emergency. Traditionally, it is either the SBP or the MAP that the clinician uses in order to make patient management decisions. Knowing that the DBP is the most accurate of the blood pressure measurements at the ankle compared to the arm, it might mean that we need to investigate how our management can be altered based on DBP targets rather than the less accurate ankle SBP or MAP if the arm is not available for BP measurement.

The MAP actual average difference between the arm and the ankle fell within the clinically acceptable error range of 10 mmHg. The ankle MAP was found to be 5 mmHg higher than the average arm MAP with a precision of 6 mmHg. Regrettably, the 95% CI show that the range extends beyond the acceptable range with values up to 13 mmHg higher in the ankle than in the arm. Percentage difference was on average 5% but up to 20% higher or 6% lower than true arm values.

Identification of associations between variables and ankle-arm BP difference

Sex

There was a larger difference between arm and ankle SBP in males than females but both were outside the clinically acceptable range. As with the overall population analysis, the DBP fared the best with the average difference as little as 1 mmHg lower noted in males. The CI for DBP for males also stayed within the clinically acceptable range, but was noted to extend to 15 mmHg lower in the female population group thus making it clinically unacceptable. The MAP in the ankle was higher than the arm MAP in both males and females and within the clinically acceptable range on average but the CI extended beyond the clinically acceptable limits.

Age

The population was categorised to see whether increasing age had any effect on the differences in the arm and ankle blood pressures. SBP was still the poorest performing measurement with DBP and MAP both being within the clinically acceptable limits. There was no clinically significant difference between the age groups but there was a trend in the older population group towards a larger difference and therefore higher measured values in the ankle SBP. This may be as a result of the age-related development of atherosclerosis in the blood vessels.

Race

There was no link seen between race and the difference in arm and ankle SBP, DBP or MAP. The trend of large SBP differences with clinically acceptable DBP and MAP differences remained.

Height and weight

On initial evaluation of the actual and absolute average arm ankle differences, it does not appear that height and weight affected the overall pattern of SBP, DBP and MAP as their values are very similar. However, shorter and lighter patients always had a measured ankle SBP that was higher than the arm whereas as the population became taller and heavier the measured values sometimes become less than the measured arm values. This same tendency was evident in the DBP and MAP of shorter, lighter patients.

BMI

Since BMI is calculated from weight and height, the SBP inclination to be higher in the ankle than the arm consistently was echoed in patients in the normal and underweight categories of body mass index. As BMI increased, the deviation away from the general SBP trend to being greater in the ankle increased but so did the precision and bias with values up to 38 mmHg difference obtained. Although still within the clinically acceptable range, DBP and MAP CI became more spread out as the population’s BMI approached the obese and morbidly obese categories. This would mean that one could potentially look at using the DBP or MAP in thin or average body habitus patients, but with more caution in overweight patients and not at all in obese or morbidly obese patients.

Arm cuff size

Arm cuff size category divisions mirrored the findings in the weight, height and BMI categories with respect to patients that used the “small adult” or “adult” cuffs. This seems logical as arm size will normally increase as those parameters increase. Population cuff distribution was also skewed towards a larger cuff. The patients that required a larger cuff always had an SBP that was higher in the ankle than in the arm. There was, however, a tendency for the patients who used the small adult cuff to have a greater discrepancy between the arm and ankle systolic blood pressures. SBP values were outside the clinically acceptable range irrespective of cuff size. DBP differences were clinically acceptable and on average 1-2 mmHg lower than the arm with less precision and more bias seen as the required arm cuff got bigger. MAP differences reiterated SBP findings with a tendency towards smaller arm cuff patients having a larger discrepancy between the arm and ankle readings.

Ankle cuff size

Population ankle cuff usage showed a normal distribution with equal amounts of patients requiring a small adult or large adult cuff for the ankle. This shows that despite increasing weight/BMI that ankle size is not as affected as much as the arm. The same trends as discussed under arm cuff size however were seen with the ankle cuff categories.

Reason for presentation

There were no exceptions to the general trend irrespective of whether the patient presented because of a traumatic or non-traumatic complaint.

Tobacco use

Despite a smaller sub-population being questioned regarding tobacco usage, there was an almost equal distribution of smokers and non-smokers. No specific effect on the general BP trends was noted secondary to smoking.

Pulse rate

The slower the patient’s pulse rate, the greater the measured discrepancy between arm and ankle SBP and MAP became. At pulse rates of greater than 80 beats per minute, the SBP actually had a clinically acceptable average arm ankle difference. This was, however, marred by the wide confidence interval which shows that the SBP difference may be up to 23 mmHg higher in the ankle even when the patient has a pulse above 80 bpm. Average DBP and MAP differences were clinically acceptable across the pulse range. Converse to the SBP, the CI for DBP was within clinically acceptable limits for patients with pulses less than or equal to 80 bpm, but became unacceptable at rates greater than 80 bpm. Mean arterial pressure averages were clinically acceptable but had CI that exceeded clinical acceptability across the pulse range.

Arm SBP range

Arm-ankle differences of SBP were mostly higher if the measured SBP was less than or equal to 150 mmHg but were greater than the clinically acceptable error of 10 mmHg. If the SBP exceeded 150 mmHg, the measured ankle SBP was always higher than the arm but was an alarming 24 mmHg different on average but could be up to 38 mmHg different. Thus, the higher the BP, the more inaccurate the SBP would become. This was reaffirmed to a lesser extent in the MAP differences. The MAP was within the clinically acceptable range for all SBP measurements on average, but when the measured SBP was greater than 150 mmHg, so the CI for the MAP suddenly widened. Despite the acceptable average MAP differences, the absolute CI for MAP differences throughout the SBP range was greater than 10 mmHg. DBP was more reliable across the SBP range but performed best at SBP ≤120 mmHg with an average actual difference of 1 mmHg, an absolute difference of 4 mmHg and CI for both within a clinically acceptable 10 mmHg. The CI for DBP when systolic blood pressure readings were above 121 mmHg were greater than 10 mmHg. These findings may be a beneficial with regards to the DBP measurement in hypotensive patients but the lowest recorded SBP was 92 mmHg which will obviously limit this potential postulated link until validated in a hypotensive population.

Arm DBP range

The difference in arm and ankle SBP is greatest at diastolic blood pressures that are higher than 90 mmHg. The higher DBP causes the average SBP difference to increase and the CI to widen. The SBP arm ankle difference is outside the clinically acceptable range irrespective of measure DBP, but is exacerbated as the

DBP rises. Accuracy of DBP is again better at lower blood pressures. When the measured DBP is less than 70 mmHg, there is no difference between the arm and the ankle measurements with a CI of -8 to 9 which is clinically acceptable. The difference widens to 12 mmHg with DBP ≥ 71 mmHg. MAP averages are clinically acceptable throughout the DBP range, but the 95% CI are too wide for clinically acceptable application. At higher DBP, the MAP differences are accentuated.

Arm MAP range

SBP accuracy and reliability is not dependent on MAP range. SBP differences are not clinically acceptable irrespective of the MAP reading. There is a tendency towards an exaggeration in the inaccuracy when measured MAP is ≥ 111 mmHg. DBP differences are non-existent on average when MAP is less than 87 mmHg with a clinically acceptable range of difference of less than 10 mmHg. There is a slight difference at measured mean arterial pressures between 87 and 110 mmHg, with the CI increasing past the clinically acceptable range at MAP ≥ 111 mmHg. DBP measured at the ankle is therefore reasonably accurate and precise if the arm MAP is less than 110 mmHg.

Regression formula

Multiple regression may help determine whether there are specific variables that may be used in order to predict the arm SBP, DBP and MAP.

Multiple regression analyses were performed to determine how much variance there was in arm measurements for systolic, diastolic and mean arterial blood pressures compared to all the variables that were collected i.e. age, race, height, weight, BMI, arm cuff size, ankle cuff size, reason for presentation, tobacco usage and pulse rate.

The main contributor to arm SBP measurement prediction was found to be the ankle SBP but arm circumference and the patient's weight also contributed. The contribution by arm circumference was echoed in the regression formula derived from a paediatric population proposed by Schell *et al.* which also included neurological diagnosis in a comparison between arm and ankle BP. It unfortunately only had an r^2 value of 0.123 [50].

The main determinant of arm DBP prediction was ankle DBP, with contributions from height and ankle circumference.

Arm MAP could be predicted with the main contribution from ankle MAP, assisted by pulse and arm circumference. This showed the best prediction amongst the three readings at with an r^2 value of 0.87. The advantage that MAP has is probably as a result of it being the only value directly measured by the oscillometric machine, with both SBP and DBP being calculated from this value. Schell *et al.* also found that arm circumference partially predicted arm and calf BP differences in their regression formula derived from a paediatric population [50].

Although these regression formulae may allow the user to believe that the arm and ankle blood pressures can be linked with a reasonable accuracy, there are potential problems with disseminating them for general use: –

1. The results again may seem reasonable when applied to the population, but may be dangerous if applied to the individual patient
2. It will be impractical, cumbersome and time-consuming to attempt to accurately obtain the relevant variables for the formulae (e.g. height, weight, arm and ankle circumference) in the resuscitation setting
3. The formulae are liable to errors in calculation due to their complexity. They are also time-consuming to perform. Inclusion of the formulae in a mobile phone application may alleviate some of these issues, but the ends seemingly do not justify the effort.
4. The study population from which the formulae were derived is not sufficiently large enough to create robust formulae that can work in all circumstances.

Correlation analysis

Correlation analysis is not a good method for determining the accuracy of blood pressure (or any) measurements relative to one another. Correlation with regards to this data is meant to show often the ankle BP gets bigger as the arm BP gets bigger. Although there seems to be reasonable correlation between the arm and ankle SBP (r^2 0.79), the arm and ankle DBP (r^2 0.77) and the arm and ankle MAP (r^2 0.85) as depicted in figures 4.1, 4.2 and 4.3, there are a considerable number of patients who fall outside acceptable range of BP differences by this method of analysis. These findings demonstrate that the general trend in the patient population is as arm SBP, DBP and MAP increase, so do ankle SBP, DBP and MAP but the link between the two limbs is not accurate to a clinically acceptable degree.

Systolic blood pressures had the greatest differences between arm and ankle measurements whereas diastolic blood pressure had the least difference making it a more accurate predictor of the blood pressure. This is not evidenced in the correlation analysis where the poorest correlation is noted in DBP.

The difference between arm and ankle BP had no significant correlation with age, height, weight, BMI, pulse rate, arm or ankle circumferences.

The correlation analysis of these results does not, however, show the consistency and reliability of the relationship between arm and ankle blood pressure measurements. It would not be prudent to base using ankle measurements interchangeably with arm measurements on a correlation analysis. This is where the Bland and Altman analysis is a better comparative tool.

Bland and Altman analysis

The Bland-Altman analysis for SBP had an average error of -13 mmHg which is not clinically acceptable as well as wide limits of agreement (-28 to 1). This means that the SBP value obtained in the ankle should not be used clinically at all as a substitute for arm SBP.

Bland-Altman analysis for DBP showed promising results with an average error of 2 mmHg with limits of agreement -7 to 10 mmHg. Not only is the average error within the clinically acceptable range, but the narrow limits of agreement are also. Therefore when measuring DBP on a patient’s ankle, one could be 95% certain that the arm DBP was within the clinically acceptable range however, it would not be known whether it was higher or lower than the measured ankle value.

When the MAP values were assessed via Bland-Altman analysis, the average error was found to be 5 mmHg higher in the ankle which is clinically acceptable. Unfortunately, the limits of agreement (-13 to 4) extended beyond the clinically acceptable range, making MAP determination in the arm from an ankle reading less reliable.

Non-parametric analysis performance

The systolic, diastolic and mean blood pressures were evaluated to assess how often the differences between the arm and ankle measurements were within the clinically acceptable range of 10 mmHg.

Sixty per cent of SBP measurements in the ankle were greater than 10 mmHg different from the arm SBP measurement. Measurements were only within the clinically acceptable error range in 40% of SBP measurements.

Conversely, DBP ankle readings were within 10 mmHg in the majority of readings (95%). MAP ankle readings were also within 10 mmHg from the arm MAP in the majority of readings (84%).

As can be seen in Figure 4.8, SBP readings in the ankle are mainly higher than the arm with the majority being 10-20 mmHg higher than the measured arm SBP. On the contrary, diastolic BP readings in the ankle are mainly lower in the ankle than in the arm with the majority being up to 5 mmHg lower in the ankle. The bulk of ankle MAP readings were higher in the ankle than in the arm primarily 10 mmHg higher.

Figure 4.9 depicts the absolute differences between the arm and ankle blood pressures. It clearly demonstrates the higher precision of DBP estimation with the difference within 10 mmHg but predominantly within 5 mmHg. MAP prediction is primarily within 10 mmHg but to a lesser extent than DBP. The minority of SBP readings are within 5 mmHg with a small percentage of the total being within 10 mmHg.

Development of a correction factor “Rule-of-thumb” for SBP and MAP

The use of a correction factor is a potential method to improve the accuracy of SBP and MAP. It removes the need to remember a complex formula like that derived from multiple regression. The accuracy of DBP was already clinically acceptable and therefore would not benefit from implementation of a correction factor.

In this case, a correction factor of 15 mmHg improved arm SBP prediction from being clinically acceptable in 40% of the patient population to 74% of the population. Despite this significant increase, this still means that 26% of the population will have a measured ankle SBP that differs clinically significantly from the arm SBP. It will not be evident to an end user whether their patient is part of the 26% of the population with an inaccurately measured SBP.

Correction of ankle MAP by a factor of 5 mmHg improved the accuracy of ankle MAP to include 95% of the population. This then makes ankle MAP as accurate as ankle DBP. Ninety-five percent of the population will have an arm MAP within 5 mmHg of the corrected ankle MAP. This then can potentially be applied to the clinical setting.

Why is the ankle SBP generally higher than the arm SBP?

There are various potential reasons why the ankle SBP is generally higher than the arm SBP:-

- The ankle reading may be inaccurate due to inability of the cuff to compress the dorsalis pedis/posterior tibial artery.
- Differences in subcutaneous fat and/or muscle may interfere with compression of the artery and detection of the oscillations.
- The arterial pulsations may be muffled.
- BP is potentially increased due to the higher resistance from the decreased radius of more distal vessels (Law of LaPlace).
- Hydrostatic pressure and the relative position of the arm, ankle and heart to one another can cause increases in the ankle SBP.

End points of resuscitation – mean vs systolic vs diastolic BP targets

The common theme amongst BP targets in the emergency setting is either the use of SBP or MAP target.

For example, in a hypotensive polytrauma patient being resuscitated in the ED, in order not to “pop the clot” it was initially advised not raise the SBP greater than

100 mmHg as part of “permissive hypotension” which subsequently became maintaining MAP at approximately 65 mmHg [118, 119]. This has now been extended to a suggested MAP of as low as 50 mmHg as part of “damage control resuscitation” [120, 121].

This is different from a patient with acute coronary syndrome and hypertensive emergency who requires their SBP brought down to below 180 mmHg in order to decrease the risk of intra-cerebral haemorrhage from thrombolysis. Hypertensive emergency management also requires that the MAP not get decreased by more than 25% of the original reading and that the DBP is not dropped below 110 mmHg in order to prevent a watershed infarct from sudden cerebral hypoperfusion.

One also needs to consider the septic patient who requires early goal-directed therapy. The aim in these patients is to raise the MAP to 65 mmHg with fluids and vasoactive agents as part of the treatment bundle for the patient with severe sepsis and septic shock [122].

In each of these cases, differences between a measured arm and ankle BP of more than 10 mmHg higher or lower could significantly change management goals for the patient and therefore could potentially have deleterious effects if the wrong management is instituted based on a falsely high or falsely low BP.

Perhaps knowing that ankle DBP values are a more accurate representation of arm DBP based on the abovementioned data, research needs to be more focused on diastolic blood pressure targets.

Clinically acceptable BP differences

Although many people consider a difference in values of more than or equal to 10 mmHg between actual and measured BP values, the acceptability thereof may be different if the individual components of the blood pressures are scrutinised e.g. an SBP of 100 mmHg vs 110 mmHg does not evoke the same response as an SBP of 90 mmHg vs 80 mmHg or 160 mmHg vs 170 mmHg. This is similar to mean arterial pressure whereby a MAP of 60 mmHg is quite different from a MAP of 50 mmHg. Perhaps a difference of more than 5 mmHg should be considered to be clinically significant for MAP. So then it is not only the individual components of the blood pressure that make a difference but also what level is being compared i.e. hypotension, normotension or hypertension.

Calibration of arm with ankle blood pressures

Wilkes and DiPalma suggested that the ankle can be used as an alternative to the arm should the arm not be available “recognising that the readings are generally higher than the corresponding brachial pressures” [14]. The problem with this suggestion, as can be seen from the data, is that the “general rule” does not always apply.

A personal practice offered by one of the authors from the Moore *et al*. study is to initially take the blood pressure in the arm before proceeding to the ankle in order to get an idea of the degree of difference between the 2 sites [95]. While this may seem like a logical option, there are two inherent problems:-

1. In the ED it is not always feasible to take the initial arm blood pressure measurement for comparison.
2. There is no guarantee that the initial difference in readings noted will remain consistent throughout the resuscitation.

Perhaps the fate of BP will parallel what has become of central venous pressure as an indicator for fluid status – being used as a trend rather than taken as an absolute based on one reading.

The use of multiple linear regression is unlikely to be applicable to the clinical setting but a correction factor may be a feasible alternative option. The correction factors may not hold over the complete range of blood pressures. Further research is required to validate this.

Limitations of this study

- This study only evaluated patients with non-life-threatening conditions in the ED which may preclude its extrapolation to hypotensive or hypertensive critically ill or injured patients.
- The sample size was too small in order to draw conclusions based on regression analysis.
- The blood pressure in the ankle was compared to the NIBP of the arm and not the intra-arterial actual BP.

Strengths of this study

- Single observer documented all readings thereby preventing inter-observer variability.
- All patients were positioned the same throughout all the BP measurements.
- The same NIBP machine and BP cuffs were used for all patients.

Direct patient benefits of this study

If a patient was found to have an elevated blood pressure during data collection, they were advised to go for a check-up after their acute problem had resolved due to the dangers of undiagnosed and untreated hypertension. Patients who admitted to being hypertensive and had a high measured blood pressure were counselled on the importance of compliance with their medication. Patients who were smokers were counselled regarding the negative sequelae of smoking and advised on the topic of smoking cessation.

Chapter 6 CONCLUSIONS

A comparison of blood pressure in the arm and ankle in patients in the ED has shown that, in general, the ankle blood pressure cannot be used interchangeably with the arm blood pressure.

The most reliable reading that can be obtained at the ankle is the diastolic blood pressure which unfortunately does not have many clinical applications as a target in the resuscitation setting.

Although the ankle can be seen as a convenient alternative site to the arm in the resuscitation environment, it seems to be too distal in order to give a meaningful value.

Linear regression formulas might be an option but are cumbersome. Rule-of-thumb techniques seem feasible but there is no guarantee that the relationship between the arm and ankle BP will hold true when there are changes in actual BP, heart rate or other variables.

The search for an accurate, instantaneous, easily repeatable, quickly obtainable, non-invasive measure of blood pressure must still continue or an alternative monitoring modality to blood pressure should be sought in order to solve this conundrum.

Recommendations

1. Ensure the correct cuff size is used.
2. Make use of a manual blood pressure cuff for initial BP measurements in all critically ill or injured patients.
3. If the BP cuff was placed on the ankle initially in the resuscitation, ensure that it is transferred to an arm when feasible.
4. If the patient remains critical, place an intra-arterial cannula to monitor BP invasively.
5. If the BP cuff is to remain on the ankle, remember that the only potentially reliable reading is the DBP.
6. BP readings on the ankle become more inaccurate in taller, heavier and fatter patients.
7. The ankle BP readings are more inaccurate with higher blood pressures.
8. Keep all BP machines (manual and oscillometric) calibrated and in good working order.
9. A rule-of-thumb correction factor may be used with caution in correcting measured ankle SBP and MAP.

Chapter 7 REFERENCES

1. Gardner AW, Afaq A. Management of lower extremity peripheral arterial disease. J Cardiopulm Rehabil Prev. 2008 Nov-Dec;28(6):349-57.
2. Moore K.L., Dalley A.F. Clinically Oriented Anatomy. 5th ed: Lippincott Williams & Wilkins; 2006.
3. Macfarlane JT. BTS Guidelines for the Management of Community Acquired Pneumonia in Adults. Thorax. 2001 Dec;56 Suppl 4:IV1-64.
4. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet. 1986 Feb 8;1(8476):307-10.
5. Perloff D, Grim C, Flack J, Frohlich ED, Hill M, McDonald M*, et al.* Human blood pressure determination by sphygmomanometry. Circulation. 1993 Nov;88(5 Pt 1):2460-70.
6. Pickering TG, Hall JE, Appel LJ, Falkner BE, Graves J, Hill MN*, et al.* Recommendations for blood pressure measurement in humans and experimental animals: Part 1: blood pressure measurement in humans: a statement for professionals from the Subcommittee of Professional and Public Education of the American Heart Association Council on High Blood Pressure Research. Hypertension. 2005 Jan;45(1):142-61.
7. Williams JS, Brown SM, Conlin PR. Videos in clinical medicine. Blood-pressure measurement. N Engl J Med. 2009 Jan 29;360(5):e6.
8. Beevers G, Lip GY, O'Brien E. ABC of hypertension. Blood pressure measurement. Part I-sphygmomanometry: factors common to all techniques. BMJ. 2001 Apr 21;322(7292):981-5.

9. Burdick W, Clarke N, Garlichs R, Priestly J, Richards D. Differences in blood pressure in the arm and leg in normal subjects. Am J Physiol. 1925;72:169-76.

10. Zahn J, Bernstein H, Hossain S, Bodian C, Beilin Y. Comparison of non-invasive blood pressure measurements on the arm and calf during cesarean delivery. J Clin Monit Comput. 2000;16(8):557-62.

11. Sanghera S, North A, Abernethy S, Wrench I. Arm and ankle blood pressure during caesarean section. Int J Obstet Anesth. 2006 Jan;15(1):24-7.

12. Short JA. Noninvasive blood pressure measurement in the upper and lower limbs of anaesthetized children. Paediatr Anaesth. 2000;10(6):591-3.

13. Crapanzano MS, Strong WB, Newman IR, Hixon RL, Casal D, Linder CW. Calf blood pressure: clinical implications and correlations with arm blood pressure in infants and young children. Pediatrics. 1996 Feb;97(2):220-4.

14. Wilkes JM, DiPalma JA. Brachial blood pressure monitoring versus ankle monitoring during colonoscopy. South Med J. 2004 Oct;97(10):939-41.

15. Block FE, Schulte GT. Ankle blood pressure measurement, an acceptable alternative to arm measurements. Int J Clin Monit Comput. 1996 Aug;13(3):167-71.

16. Chobanian AV, Bakris GL, Black HR, Cushman WC, Green LA, Izzo JL, Jr., *et al.* The Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure: the JNC 7 report. Jama. 2003 May 21;289(19):2560-72.

17. Backer HD, Decker L, Ackerson L. Reproducibility of increased blood pressure during an emergency department or urgent care visit. Ann Emerg Med. 2003 Apr;41(4):507-12.

18. Geddes LA. Why do we measure blood pressure in millimeters of mercury? IEEE Eng Med Biol Mag. 2008 Jan-Feb;27(1):70, 86.

19. Geddes LA. The first accurate measurement of systolic and diastolic blood pressure. IEEE Eng Med Biol Mag. 2002 May-Jun;21(3):102-3.

20. Geddes LA. Counterpressure: the concept that made the indirect measurement of blood pressure possible. IEEE Eng Med Biol Mag. 1998 Nov-Dec;17(6):85-7.

21. Westhorpe RN, Ball C. Blood pressure monitoring--automated non-invasive blood pressure monitors. Anaesth Intensive Care. 2009 May;37(3):343.

22. Ramsey M, 3rd. Noninvasive automatic determination of mean arterial pressure. Med Biol Eng Comput. 1979 Jan;17(1):11-8.

23. Ganong WF. Review of Medical Physiology. 22nd ed: Lange Medical Books/McGraw-Hill; 2005.

24. Martin EA. Oxford Concise Medical Dictionary. 4th ed. Oxford University Press, 1996: 80.

25. Razminia M, Trivedi A, Molnar J, Elbzour M, Guerrero M, Salem Y*, et al.* Validation of a new formula for mean arterial pressure calculation: the new formula is superior to the standard formula. Catheter Cardiovasc Interv. 2004 Dec;63(4):419-25.

26. Winters ME, McCurdy MT, Zilberstein J. Monitoring the critically ill emergency department patient. Emerg Med Clin North Am. 2008 Aug;26(3):741-57, ix.

27. Ogedegbe G, Pickering T. Principles and techniques of blood pressure measurement. Cardiol Clin. 2010 Nov;28(4):571-86.

28. Jones DW, Appel LJ, Sheps SG, Roccella EJ, Lenfant C. Measuring blood pressure accurately: new and persistent challenges. Jama. 2003 Feb 26;289(8):1027-30.

29. Yarows SA, Qian K. Accuracy of aneroid sphygmomanometers in clinical usage: University of Michigan experience. Blood Press Monit. 2001 Apr;6(2):101-6.

30. Waugh JJ, Gupta M, Rushbrook J, Halligan A, Shennan AH. Hidden errors of aneroid sphygmomanometers. Blood Press Monit. 2002 Dec;7(6):309-12.

31. Ng KG, Small CF. Survey of automated noninvasive blood pressure monitors. J Clin Eng. 1994 Nov-Dec;19(6):452-75.

32. Ursino M, Cristalli C. A mathematical study of some biomechanical factors affecting the oscillometric blood pressure measurement. IEEE Trans Biomed Eng. 1996 Aug;43(8):761-78.

33. Pickering TG. Blood pressure variability and ambulatory monitoring. Curr Opin Nephrol Hypertens. 1993 May;2(3):380-5.

34. Geddes LA, Voelz M, Combs C, Reiner D, Babbs CF. Characterization of the oscillometric method for measuring indirect blood pressure. Ann Biomed Eng. 1982;10(6):271-80.

35. Yamakoshi K, Tanaka S. Standard algorithm of blood-pressure measurement by the oscillometric method. Med Biol Eng Comput. 1993 Mar;31(2):204.

36. Amoore JN, Geake WB, Scott DH. Oscillometric non-invasive blood pressure measurements: the influence of the make of instrument on readings? Med Biol Eng Comput. 1997 Mar;35(2):131-4.

37. Beevers G, Lip GY, O'Brien E. ABC of hypertension: Blood pressure measurement. Part II-conventional sphygmomanometry: technique of auscultatory blood pressure measurement. BMJ. 2001 Apr 28;322(7293):1043-7.

38. VonRecklinghausen. Unblutige Blutdruckmessung. Archiv f exp Path u Pharmakol. 1906;5:325-504.

39. O'Brien E. Review: a century of confusion; which bladder for accurate blood pressure measurement? J Hum Hypertens. 1996 Sep;10(9):565-72.

40. O'Brien E, Asmar R, Beilin L, Imai Y, Mallion JM, Mancia G*, et al.* European Society of Hypertension recommendations for conventional, ambulatory and home blood pressure measurement. J Hypertens. 2003 May;21(5):821-48.

41. Marks LA, Groch A. Optimizing cuff width for noninvasive measurement of blood pressure. Blood Press Monit. 2000 Jun;5(3):153-8.

42. Carescape V100 Vital Signs Monitor Service Manual [Manual]: General Electric Company; 2008.

43. Amoore JN, Guehenec M, Scordecchia R, Scott DH. Auditing the technology used to measure blood pressure. J Med Eng Technol. 2010 Apr;34(3):209-16.

44. Adiseshiah M, Cross FW, Belsham PA. Ankle blood pressure measured by automatic oscillotonometry: a comparison with Doppler pressure measurements. Ann R Coll Surg Engl. 1987 Nov;69(6):271-3.

45. Katz S, Globerman A, Avitzour M, Dolfin T. The ankle-brachial index in normal neonates and infants is significantly lower than in older children and adults. J Pediatr Surg. 1997 Feb;32(2):269-71.

46. Sadove MS, Schmidt G, Wu HH, Katz D. Indirect blood-pressure measurement in infants: a comparison of four methods in four limbs. Anesth Analg. 1973 Jul-Aug;52(4):682-9.

47. Crossland DS, Furness JC, Abu-Harb M, Sadagopan SN, Wren C. Variability of four limb blood pressure in normal neonates. Arch Dis Child Fetal Neonatal Ed. 2004 Jul;89(4):F325-7.

48. de Swiet M, Peto J, Shinebourne EA. Difference between upper and lower limb blood pressure in normal neonates using Doppler technique. Arch Dis Child. 1974 Sep;49(9):734-5.

49. Park MK, Robotham JL, German VF. Systolic pressure amplification in pedal arteries in children. Crit Care Med. 1983 Apr;11(4):286-9.

50. Schell K, Briening E, Lebet R, Pruden K, Rawheiser S, Jackson B. Comparison of arm and calf automatic noninvasive blood pressures in pediatric intensive care patients. J Pediatr Nurs. 2011 Feb;26(1):3-12.

51. Nuessle WF. The importance of a tight blood pressure cuff. Am Heart J. 1956 Dec;52(6):905-7.

52. King GE. Errors in clinical measurement of blood pressure in obesity. Clin Sci (Lond). 1967 Apr;32(2):223-37.

53. Kahan E, Yaphe J, Knaani-Levinz H, Weingarten MA. Comparison of blood pressure measurements on the bare arm, below a rolled-up sleeve, or over a sleeve. Fam Pract. 2003 Dec;20(6):730-2.

54. Archer LJ, Smith AJ. Blood pressure measurement in volunteers with and without padding between the cuff and the skin. Anaesthesia. 2001 Sep;56(9):847-9.

55. Wertheim D, Trenary K, Melhuish J, Williams R, Harding K. Ankle systolic blood pressure measurement and cuff application. Lancet. 1996 Jun 29;347(9018):1845-6.

56. Mundt KA, Chambless LE, Burnham CB, Heiss G. Measuring ankle systolic blood pressure: validation of the Dinamap 1846 SX. Angiology. 1992 Jul;43(7):555-66.

57. Takahashi O, Shimbo T, Rahman M, Okamoto S, Tanaka Y, Fukui T. Evaluation of cuff-wrapping methods for the determination of ankle blood pressure. Blood Press Monit. 2006 Feb;11(1):21-6.

58. Adiyaman A, Verhoeff R, Lenders JW, Deinum J, Thien T. The position of the arm during blood pressure measurement in sitting position. Blood Press Monit. 2006 Dec;11(6):309-13.

59. Dawber TR, Meadors GF, Moore FE, Jr. Epidemiological approaches to heart disease: the Framingham Study. Am J Public Health Nations Health. 1951 Mar;41(3):279-81.

60. Guss DA, Abdelnur D, Hemingway TJ. The impact of arm position on the measurement of orthostatic blood pressure. J Emerg Med. 2008 May;34(4):377-82.

61. Parr GD, Poole PH. Effects of sphygmomanometer type and position of the arm on blood pressure measurement. J Hum Hypertens. 1988 Oct;2(3):153-6.

62. Mourad A, Carney S, Gillies A, Jones B, Nanra R, Trevillian P. Arm position and blood pressure: a risk factor for hypertension? J Hum Hypertens. 2003 Jun;17(6):389-95.

63. Ljungvall P, Thorvinger B, Thulin T. The influence of a heart level pillow on the result of blood pressure measurement. J Hum Hypertens. 1989 Dec;3(6):471-4.

64. Adiyaman A, Tosun N, Elving LD, Deinum J, Lenders JW, Thien T. The effect of crossing legs on blood pressure. Blood Press Monit. 2007 Jun;12(3):189-93.

65. Pinar R, Sabuncu N, Oksay A. Effects of crossed leg on blood pressure. Blood Press. 2004;13(4):252-4.

66. Hemingway TJ, Guss DA, Abdelnur D. Arm position and blood pressure measurement. Ann Intern Med. 2004 Jan 6;140(1):74-5.

67. Cushman WC, Cooper KM, Horne RA, Meydrech EF. Effect of back support and stethoscope head on seated blood pressure determinations. Am J Hypertens. 1990 Mar;3(3):240-1.

68. Netea RT, Smits P, Lenders JW, Thien T. Does it matter whether blood pressure measurements are taken with subjects sitting or supine? J Hypertens. 1998 Mar;16(3):263-8.

69. Terent A, Breig-Asberg E. Epidemiological perspective of body position and arm level in blood pressure measurement. Blood Press. 1994 May;3(3):156-63.

70. Halliwill JR, Hewitt SA, Joyner MJ, Warner MA. Effect of various lithotomy positions on lower-extremity blood pressure. Anesthesiology. 1998 Dec;89(6):1373-6.

71. Padfield PL, Jyothinagaram SG, Watson DM, Donald P, McGinley IM. Problems in the measurement of blood pressure. J Hum Hypertens. 1990 Jun;4 Suppl 2:3-7.

72. Pickering TG. Principles and techniques of blood pressure measurement. Cardiol Clin. 2002 May;20(2):207-23.

73. Parati G, Ulian L, Santucciu C, Omboni S, Mancia G. Difference between clinic and daytime blood pressure is not a measure of the white coat effect. Hypertension. 1998 May;31(5):1185-9.

74. Cienki JJ, DeLuca LA, Daniel N. The validity of emergency department triage blood pressure measurements. Acad Emerg Med. 2004 Mar;11(3):237-43.

75. King GE. Influence of rate of cuff inflation and deflation on observed blood pressure by sphygmomanometry. Am Heart J. 1963 Mar;65:303-6.

76. Zheng D, Amoore JN, Mieke S, Murray A. How important is the recommended slow cuff pressure deflation rate for blood pressure measurement? Ann Biomed Eng. 2011 Oct;39(10):2584-91.

77. Anastas ZM, Jimerson E, Garolis S. Comparison of noninvasive blood pressure measurements in patients with atrial fibrillation. J Cardiovasc Nurs. 2008 Nov-Dec;23(6):519-24; quiz 25-6.

78. Hamad M, Freeman R, Wrench I. Incidence of failure of upper limb automated blood pressure measurement during Caesarean Section. Int J Obstet Anesth. 2001;10:218.

79. Bur A, Herkner H, Vlcek M, Woisetschlager C, Derhaschnig U, Delle Karth G*, et al.* Factors influencing the accuracy of oscillometric blood pressure measurement in critically ill patients. Crit Care Med. 2003 Mar;31(3):793-9.

80. Elseed AM, Shinebourne EA, Joseph MC. Assessment of techniques for measurement of blood pressure in infants and children. Arch Dis Child. 1973 Dec;48(12):932-6.

81. Araghi A, Bander JJ, Guzman JA. Arterial blood pressure monitoring in overweight critically ill patients: invasive or noninvasive? Crit Care. 2006;10(2):R64.

82. Tholl U, Forstner K, Anlauf M. Measuring blood pressure: pitfalls and recommendations. Nephrol Dial Transplant. 2004 Apr;19(4):766-70.

83. Carney SL, Gillies AH, Green SL, Paterson O, Taylor MS, Smith AJ. Hospital blood pressure measurement: staff and device assessment. J Qual Clin Pract. 1999 Jun;19(2):95-8.

84. Canzanello VJ, Jensen PL, Schwartz GL. Are aneroid sphygmomanometers accurate in hospital and clinic settings? Arch Intern Med. 2001 Mar 12;161(5):729-31.

85. Bur A, Hirschl MM, Herkner H, Oschatz E, Kofler J, Woisetschlager C*, et al.* Accuracy of oscillometric blood pressure measurement according to the relation between cuff size and upper-arm circumference in critically ill patients. Crit Care Med. 2000 Feb;28(2):371-6.

86. Gibbs NM, Larach DR, Derr JA. The accuracy of Finapres noninvasive mean arterial pressure measurements in anesthetized patients. Anesthesiology. 1991 Apr;74(4):647-52.

87. Kaufmann MA, Pargger H, Drop LJ. Oscillometric blood pressure measurements by different devices are not interchangeable. Anesth Analg. 1996 Feb;82(2):377-81.

88. O'Brien E. A website for blood pressure measuring devices: dableducational.com. Blood Press Monit. 2003 Aug;8(4):177-80.

89. Sims AJ, Menes JA, Bousfield DR, Reay CA, Murray A. Automated non-invasive blood pressure devices: are they suitable for use? Blood Press Monit. 2005 Oct;10(5):275-81.

90. Sims AJ, Reay CA, Bousfield DR, Menes JA, Murray A. Low-cost oscillometric non-invasive blood pressure monitors: device repeatability and device differences. Physiol Meas. 2005 Aug;26(4):441-5.

91. Thien T, Adiyaman A, Staessen JA, Deinum J. Blood pressure measurement in the year 2008: revival of oscillometry? Neth J Med. 2008 Dec;66(11):453-6.

92. Schell K, Bradley E, Bucher L, Seckel M, Lyons D, Wakai S*, et al.* Clinical comparison of automatic, noninvasive measurements of blood pressure in the forearm and upper arm. Am J Crit Care. 2005 May;14(3):232-41.

93. Singer AJ, Kahn SR, Thode HC, Jr., Hollander JE. Comparison of forearm and upper arm blood pressures. Prehosp Emerg Care. 1999 Apr-Jun;3(2):123-6.

94. Sanghera S, Abernethy S, North A, Wrench I. To compare the measurement of blood pressure on the upper arm and ankle during lower segment caesarean section under spinal anaesthesia. Int J Obstet Anesth. 2002;11:7.

95. Moore C, Dobson A, Kinagi M, Dillon B. Comparison of blood pressure measured at the arm, ankle and calf. Anaesthesia. 2008 Dec;63(12):1327-31.

96. Parry T, Hirsch N, Fauvel N. Comparison of direct blood pressure measurement at the radial and dorsalis pedis arteries during surgery in the horizontal and reverse Trendelenburg positions. Anaesthesia. 1995 Jun;50(6):553-5.

97. Anderson I. The effect of varying cuff position on recording ankle systolic blood pressure. J Wound Care. 2002 May;11(5):185-9.

98. Clark CE, Campbell JL, Evans PH, Millward A. Prevalence and clinical implications of the inter-arm blood pressure difference: A systematic review. J Hum Hypertens. 2006 Dec;20(12):923-31.

99. Chang JJ, Rabinowitz D, Shea S. Sources of variability in blood pressure measurement using the Dinamap PRO 100 automated oscillometric device. Am J Epidemiol. 2003 Dec 15;158(12):1218-26.

100. Kawamura T. Assessing Ankle-Brachial Index (ABI) by using automated oscillometric devices. Arq Bras Cardiol. 2008 May;90(5):294-8.

101. Hager H, Mandadi G, Pulley D, Eagon JC, Mascha E, Nutter B*, et al.* A comparison of noninvasive blood pressure measurement on the wrist with invasive arterial blood pressure monitoring in patients undergoing bariatric surgery. Obes Surg. 2009 Jun;19(6):717-24.

102. Shahriari M, Rotenberg DK, Nielsen JK, Wiinberg N, Nielsen PE. Measurement of arm blood pressure using different oscillometry manometers compared to auscultatory readings. Blood Press. 2003;12(3):155-9.

103. Schell K, Morse K, Waterhouse JK. Forearm and upper-arm oscillometric blood pressure comparison in acutely ill adults. West J Nurs Res. 2010 Apr;32(3):322-40.

104. Schell K, Lyons D, Bradley E, Bucher L, Seckel M, Wakai S*, et al.* Clinical comparison of automatic, noninvasive measurements of blood pressure in the forearm and upper arm with the patient supine or with the head of the bed raised 45 degrees: a follow-up study. Am J Crit Care. 2006 Mar;15(2):196-205.

105. Domiano KL, Hinck SM, Savinske DL, Hope KL. Comparison of upper arm and forearm blood pressure. Clin Nurs Res. 2008 Nov;17(4):241-50.

106. Pierin AM, Alavarce DC, Gusmao JL, Halpern A, Mion D, Jr. Blood pressure measurement in obese patients: comparison between upper arm and forearm measurements. Blood Press Monit. 2004 Jun;9(3):101-5.

107. Palatini P, Longo D, Toffanin G, Bertolo O, Zaetta V, Pessina AC. Wrist blood pressure overestimates blood pressure measured at the upper arm. Blood Press Monit. 2004 Apr;9(2):77-81.

108. Mourad A, Gillies A, Carney S. Inaccuracy of wrist-cuff oscillometric blood pressure devices: an arm position artefact? Blood Press Monit. 2005 Apr;10(2):67-71.

109. Khoshdel AR, Carney S, Gillies A. The impact of arm position and pulse pressure on the validation of a wrist-cuff blood pressure measurement device in a high risk population. Int J Gen Med. 2010;3:119-25.

110. Newman AB, Siscovick DS, Manolio TA, Polak J, Fried LP, Borhani NO*, et al.* Ankle-arm index as a marker of atherosclerosis in the Cardiovascular Health Study. Cardiovascular Heart Study (CHS) Collaborative Research Group. Circulation. 1993 Sep;88(3):837-45.

111. Wilson M, Davis DP, Coimbra R. Diagnosis and monitoring of hemorrhagic shock during the initial resuscitation of multiple trauma patients: a review. J Emerg Med. 2003 May;24(4):413-22.

112. Davis JW, Davis IC, Bennink LD, Bilello JF, Kaups KL, Parks SN. Are automated blood pressure measurements accurate in trauma patients? J Trauma. 2003 Nov;55(5):860-3.

113. Caramella JP, Bernard JM, Couderc E, Berger JL, Desmonts JM. [Is automatic oscillometric measurement of blood pressure reliable in hypotension?]. Ann Fr Anesth Reanim. 1985;4(4):339-42.

114. Gourdeau M, Martin R, Lamarche Y, Tetreault L. Oscillometry and direct blood pressure: a comparative clinical study during deliberate hypotension. Can Anaesth Soc J. 1986 May;33(3 Pt 1):300-7.

115. Braam RL, Thien T. Is the accuracy of blood pressure measuring devices underestimated at increasing blood pressure levels? Blood Press Monit. 2005 Oct;10(5):283-9.

116. McBeal. GlaxoSmithKline South African National Obesity Survey. [Survey]. In press 2010.

117. de Munter JS, Agyemang C, van Valkengoed IG, Bhopal R, Stronks K. Sex difference in blood pressure among South Asian diaspora in Europe and North America and the role of BMI: a meta-analysis. J Hum Hypertens. 2011 Jul;25(7):407-17.

118. Dutton RP, Mackenzie CF, Scalea TM. Hypotensive resuscitation during active hemorrhage: impact on in-hospital mortality. J Trauma. 2002 Jun;52(6):1141-6.

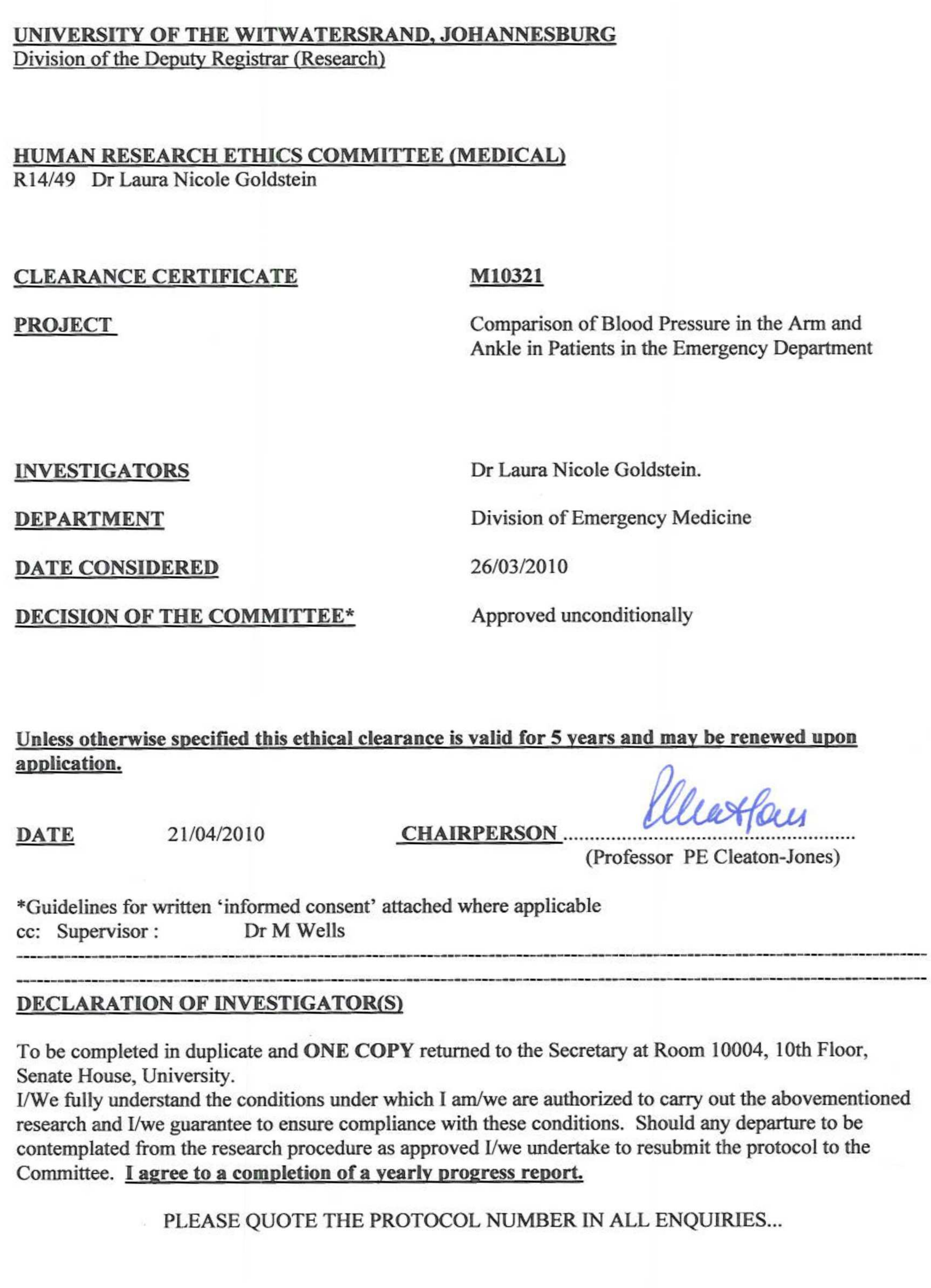
119. Bilkovski RN, Rivers EP, Horst HM. Targeted resuscitation strategies after injury. Curr Opin Crit Care. 2004 Dec;10(6):529-38.

120. Cotton BA, Reddy N, Hatch QM, LeFebvre E, Wade CE, Kozar RA*, et al.* Damage control resuscitation is associated with a reduction in resuscitation volumes and improvement in survival in 390 damage control laparotomy patients. Ann Surg. 2011 Oct;254(4):598-605.

121. Morrison CA, Carrick MM, Norman MA, Scott BG, Welsh FJ, Tsai P*, et al.* Hypotensive resuscitation strategy reduces transfusion requirements and severe postoperative coagulopathy in trauma patients with hemorrhagic shock: preliminary results of a randomized controlled trial. J Trauma. 2011 Mar;70(3):652-63.

122. Rivers E, Nguyen B, Havstad S, Ressler J, Muzzin A, Knoblich B*, et al.* Early goal-directed therapy in the treatment of severe sepsis and septic shock. N Engl J Med. 2001 Nov 8;345(19):1368-77.

APPENDIX 1 Human Research Ethics Committee clearance



UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG
Division of the Deputy Registrar (Research)

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
R14/49 Dr Laura Nicole Goldstein

CLEARANCE CERTIFICATE	**M10321**
PROJECT	Comparison of Blood Pressure in the Arm and Ankle in Patients in the Emergency Department
INVESTIGATORS	Dr Laura Nicole Goldstein.
DEPARTMENT	Division of Emergency Medicine
DATE CONSIDERED	26/03/2010
DECISION OF THE COMMITTEE*	Approved unconditionally

Unless otherwise specified this ethical clearance is valid for 5 years and may be renewed upon application.

DATE 21/04/2010 **CHAIRPERSON** ....
(Professor PE Cleaton-Jones)

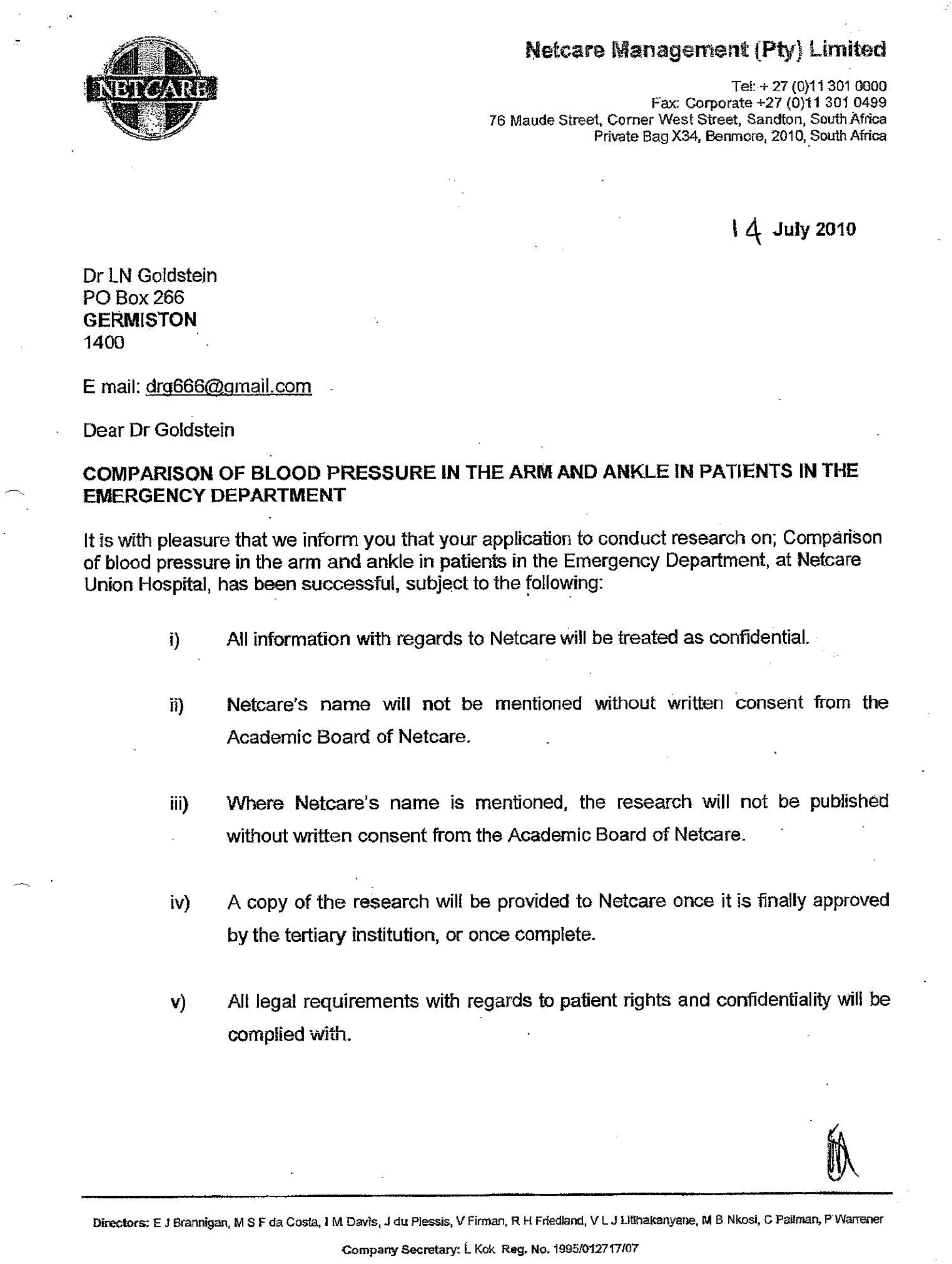
*Guidelines for written 'informed consent' attached where applicable
cc: Supervisor : Dr M Wells

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University.
I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES...

APPENDIX 2 Netcare Group Ethics Committee Clearance



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76 Maude Street, Corner West Street, Sandton, South Africa
Private Bag X34, Benmore, 2010, South Africa

14 July 2010

Dr LN Goldstein
PO Box 266
GERMISTON
1400

E mail: drg666@gmail.com

Dear Dr Goldstein

COMPARISON OF BLOOD PRESSURE IN THE ARM AND ANKLE IN PATIENTS IN THE EMERGENCY DEPARTMENT

It is with pleasure that we inform you that your application to conduct research on; Comparison of blood pressure in the arm and ankle in patients in the Emergency Department, at Netcare Union Hospital, has been successful, subject to the following:

i) All information with regards to Netcare will be treated as confidential.

ii) Netcare's name will not be mentioned without written consent from the Academic Board of Netcare.

iii) Where Netcare's name is mentioned, the research will not be published without written consent from the Academic Board of Netcare.

iv) A copy of the research will be provided to Netcare once it is finally approved by the tertiary institution, or once complete.

v) All legal requirements with regards to patient rights and confidentiality will be complied with.

Directors: E J Brannigan, M S F da Costa, I M Davis, J du Plessis, V Firman, R H Friedland, V L J Litlhakanyane, M B Nkosi, C Pailman, P Warrener

Company Secretary: L Kok **Reg. No.** 1995/012717/07

vi) I will provide a copy of insurance stating the necessary indemnity cover. This cover provided to the researcher must protect both the staff and the hospital facility from potential liability

vii) Netcare will receive a progress report by 30th September annually irrespective of the date of approval from Netcare Research Committee

We wish you success in your research.

Yours faithfully

Prof Dion du Plessis
Full member: Research Committee & Medical Practitioner evaluating research applications as per Management and Governance Policy

Shannon Nell
Chairperson: Research Committee
Network Healthcare Holdings Limited (Netcare)

APPENDIX 3 Consent Form

COMPARISON OF BLOOD PRESSURE IN THE ARM AND ANKLE IN PATIENTS IN THE EMERGENCY DEPARTMENT

I, ____, being 18 years or older, consent to participating in the research project entitled:

'COMPARISON OF BLOOD PRESSURE IN THE ARM AND ANKLE IN PATIENTS IN THE EMERGENCY DEPARTMENT'

The procedures have been explained to me and I understand and appreciate their purpose, any risks involved, and the extent of my involvement. I have read and understand the attached patient information leaflet.

I understand that the procedures form part of a research project, and may not provide any direct benefit to me.

I understand that all experimental procedures have been sanctioned by the Human Research Ethics Committee of the University of the Witwatersrand.

I understand that my participation is voluntary, and that I am free to withdraw from the project at any time without it interfering in my treatment in any way.

______________________________	____________________	____________
Subject Name	Subject Signature	Date
________Lara Goldstein___________	____________________	____________
Investigator Name	Investigator Signature	Date

APPENDIX 4 Information Sheet

COMPARISON OF BLOOD PRESSURE IN THE ARM AND ANKLE IN PATIENTS IN THE EMERGENCY DEPARTMENT

Hi!

My name is Lara Goldstein. I am a Specialist Emergency Physician conducting this study for completion of my Master of Medicine degree.

Thank you for taking the time to read this information leaflet.

Blood pressure is an important vital sign that is required to be measured in all patients presenting to the Emergency Department. This is even more crucial in a critically ill or injured patient. I would like to compare the blood pressure readings between the arms (where blood pressure is usually measured) and the ankles (where blood pressure is sometimes measured in an emergency situation). I would like to see whether there is a difference in the values obtained and potentially how this will effect patient management in the resuscitation setting.

In order to do this, I would like to invite you to participate in my study on a purely voluntary basis. It will require approximately 10 minutes of your time and will be done in a private area in the Emergency Department. You will need to lie down and rest on the bed for 5 minutes before the measurements are taken – the measurements themselves will take another 5 minutes. Your arms and ankles need to be sufficiently exposed (i.e. no clothing covering the areas) so that the blood pressure cuff can placed in these areas. You will not be required to completely disrobe.

There may be some mild discomfort felt when the cuff is inflating. There are no risks to you from participating in the study. There is no payment for taking part in the study.

I will also need the following information about you for the study, please:-

- Height
- Weight
- Reason for coming to hospital

All the data obtained during this study will be analysed and the results presented in my Masters research report as well as published in a research written paper for the scientific community. Your confidentiality will be protected at all times. The information gathered will be protected by a coded numbering system so that it remains completely anonymous. Only I will have access to the code which will be stored in a password protected computer. Any information made public (e.g. in publications or at congresses) will not reveal any details about individuals in the study.

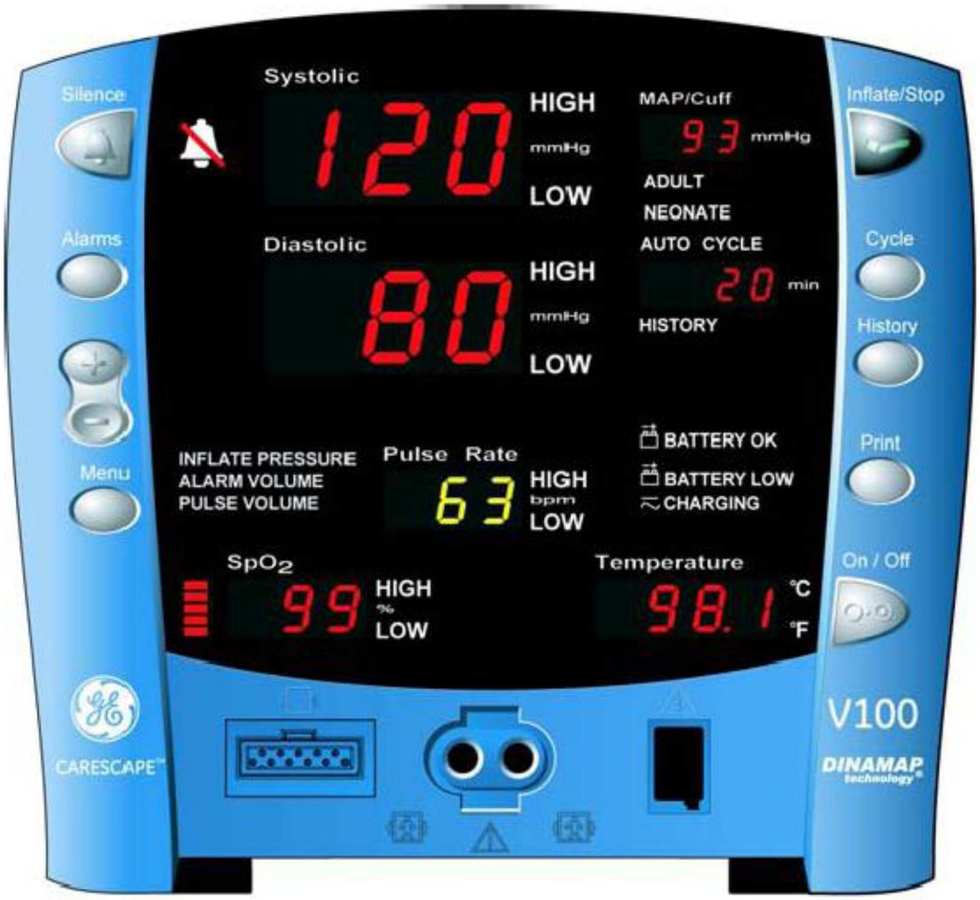
I have obtained approval for my study from the Human Research Ethics Committee of the University of the Witwatersrand. They can be contacted via Anisa Keshav, Wits Research Office, 10th Floor Senate House, East Campus at 011-717-1234 Fax: 011-717-1265 Email anisa.keshav@wits.ac.za .

Participation in this study is voluntary and you may withdraw at any time. You do not need to give a reason for withdrawing from the study. If after reading this information sheet you decide against participating in the study, please be assured that any further treatment will not be affected in any way. If you have any questions, please feel free to ask me or contact me on 082 574 5441 or email drlara666@yahoo.co.uk.

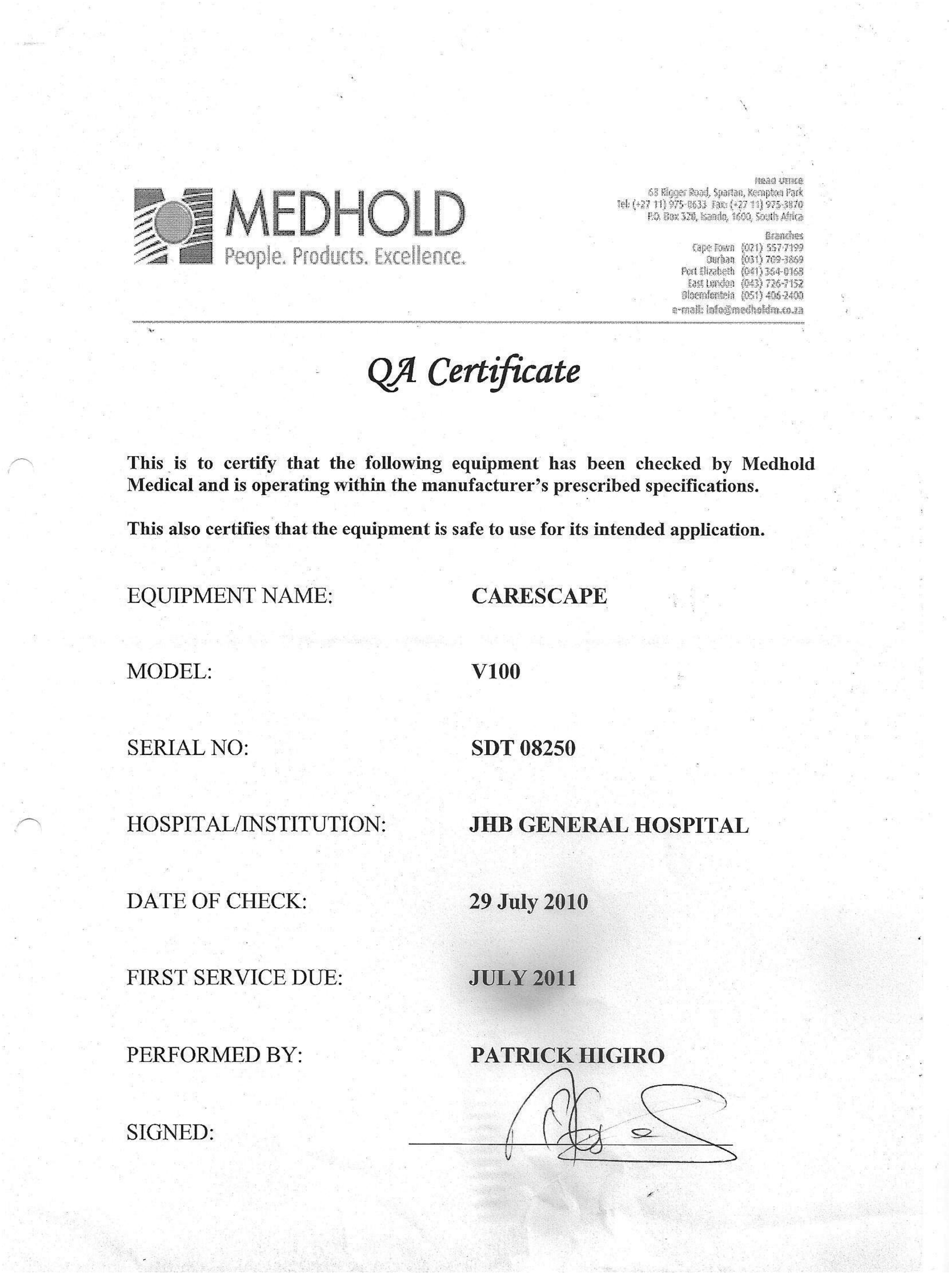
Yours sincerely
Dr Lara Goldstein

APPENDIX 6 Position of BP cuff on ankle

APPENDIX 6 Carescape V100 Vital Signs Monitor [42]



APPENDIX 7 Calibration Certificate



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QA Certificate

This is to certify that the following equipment has been checked by Medhold Medical and is operating within the manufacturer's prescribed specifications.

This also certifies that the equipment is safe to use for its intended application.

EQUIPMENT NAME: **CARESCAPE**

MODEL: **V100**

SERIAL NO: **SDT 08250**

HOSPITAL/INSTITUTION: **JHB GENERAL HOSPITAL**

DATE OF CHECK: **29 July 2010**

FIRST SERVICE DUE: **JULY 2011**

PERFORMED BY: **PATRICK HIGIRO**

SIGNED: