Validation of Weight Estimation by Age and Length based methods in the South African population

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Declaration

I confirm that *The Validation of Weight Estimation by Age and Length based methods in the South African population* is entirely my own work.

I confirm that I hold the degree MBChB from the University of Cape Town.

This dissertation is being submitted for the degree of Master of Medicine (Emergency Medicine).

I confirm that I have not submitted this dissertation for any other degree, diploma or professional qualification.

Full name:

Signature: Signed by candidate

Date:

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GLOSSARY

AHA	American Heart Association
ALSG	Advanced Life Support Group
APLS	Advanced Paediatric Life Support
BG	Best Guess Formula
BLT	Broselow® Luten Tape
BMI	Body Mass Index
BSA	Body Surface Area
CDC	Centres for Disease Control
DEPS	Duke Enhancing Paediatric Safety
ERC	European Resuscitation Council
ED	Emergency Department
ETT	Endotracheal Tube
Hb	Haemoglobin
Hct	Haematocrit
ILCOR	International Liaison Committee on Resuscitation
IMCI	Integrated Management of Childhood Illness
L&O	Luscombe and Owens formula
NCHS	National Centre for Health Statistics
NHANES	National Health and Nutrition Survey
TF	Transfusion Factor
WHO	World Health Organisation
Wt	Weight

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Abstract

Paediatric resuscitation can be a stressful event for many clinicians. It is compounded by the need to calculate accurate drug dosages and equipment sizes for many interventions. These calculations are most often based on weight, which is a difficult parameter to obtain. It is rare that one is able to weigh a child before a resuscitation.

There are many different methods available for weight estimation. Most of these are formulae based on age but length based tools are often used. Most of these formulae were derived in developed world populations and have become inaccurate due to the changing weights and heights of children.

The aim of this study was to evaluate 4 weight estimation methods (APLS, Luscombe and Owens, Best Guess and Broselow® Tape) to determine which are accurate for weight estimation in South African Children. These 4 formulae were also used to calculate the doses of adrenaline (0.1 m/kg of 1:10000), Fluid bolus (20ml/kg) and First Shock defibrillation dose (2J/Kg) to determine which were clinically useful.

A database of 3233 children between 1 and 12 years seen at Red Cross Hospital Trauma Unit in Cape Town during 2002 was used. Measured weight was compared to estimated weights from all 4 methods and Intervention doses calculated from measured weight was compared to doses from weight estimation methods.

APLS formula and the Broselow® Tape showed the best correlation with measured weight. Mean percent error – 6.4% for APLS for 1-10 year olds and -10% error for Broselow® tape in children <145cm length. Both the Best Guess and Luscombe and Owens formulae tended to overestimate weight (+13.4% and +17.6 % respectively).

The Broselow tape was most accurate for dosages of all interventions but little difference existed between methods.

The APLS and Broselow® tape are most accurate in estimating weight in the South African population, even though they have a tendency to underestimate weight.

CHAPTER 1: INTRODUCTION

Resuscitation of paediatric patients in the Emergency Department (ED) is an intimidating prospect for many Emergency Physicians. The stresses of emergency interventions are amplified by the need to individualise every step. Not only does one have to consider the anatomical and physiological differences between adults and children, but also the variation in size from infants to preteens: the range of interventions required can be daunting.

In resuscitation situations it is impractical and time consuming to weigh the child before any intervention is instituted. Access to weighing equipment may be limited; the child may be in pain, acutely ill or injured so as to exclude weighing. Calculating a reasonably accurate weight in a highly stressful environment where concentration is focused on the well-being of the child is a challenging endeavour.

Healthcare workers are notoriously bad at estimating the weight of patients (Menon *et al* 2005). Parents may be able to provide more accurate estimates of weight (Leffler 1997) but are often not available during the resuscitation event. Even in normal clinical practice, children are often not weighed before medication is prescribed: an audit of clinical notes at Kings College Hospital in London (Greig 1997) showed that only 2 out of 100 children seen in the ED had been weighed prior to medication being prescribed.

Accurate weight assessment is important. Medication in children is calculated by a formula *per kilogram* of body weight. Equipment size is determined by patient size (and, therefore, weight) and resuscitative interventions such as defibrillation energy or blood transfusion volumes are also calculated by weight in kilograms. Emergency courses such as the Advanced Paediatric Life Support (APLS) course teaches resuscitation techniques based on weight estimations (ALSG 2005). Inaccurate weight estimation leads to inaccurate drug and fluid dosages and incorrect equipment sizing.

A recent study showed that 63% of physician-related medication errors seen in children attending the ED were related to incorrect dose (Marcin *et al* 2007). This highlights a vulnerable area in emergency medical practice, particularly in treating children who may be at higher risk of adverse events related to medication errors. Under- and over-treatment with fluids and medication can result in increased morbidity and mortality; such errors also open up the practitioner to medico-legal risk.

There are multiple formulae available for estimating children's weight (Lubitz 1988, Haftel 1990, Argall 2003, Luscombe 2007, Tinning 2007). Age based formulae are the most well-known: they are simple in their design in order to be easy to memorise and use in mental calculations.

The ideal formula for weight estimation would be one that is easy to remember, easy to calculate, and accurate for the local population across all ages (Diekmann 2007). Unfortunately, this is almost impossible to achieve in practice (Kaushall 2001).

Length based formulae require measurements: these may take up valuable time before resuscitation, and consume precious human resources. However, these formulae are believed to be more accurate than age based formulae (Luten 1992). A number of formulae are based on other parameters, such as shoe size, body habitus, or a combination of different parameters (Haftel 1990, Black 2002, Carroll 2001).

The choice of which formula to use is dependent on local practice, the physicians' experience and training, or hospital policy. There is no standardised formula currently being used in South Africa: in fact, there is no evidence to support the clinical accuracy and validity of any of the commonly available weight estimation methods in our population.

All of these common weight estimation tools were developed in first world populations, and therefore may not accurately reflect our local paediatric population, which is a mix of different races and socioeconomic classes. Indeed, within South Africa we see several subgroups with different nutritional and wealth status, which is likely to affect their growth and weight. Predicting weight and growth with one easy to remember formula in this multicultural setting may be difficult.

1.1 WEIGHT ESTIMATION

Weight estimation amongst health care workers is generally poor. This uncertainty with regards to the accuracy of weight (and the drug dosages / equipment sizes derived from this) is a large part of the discomfort that is associated with treating children in emergency situations.

A recent survey of paramedics (Vilke 2001) found that 75% were uncomfortable with estimating the weight of children and that 55% were generally not confident during paediatric calls.

Emergency Department staff also score poorly when attempting to estimate children's weight. Menon showed that 78% of nurses and only 59% of doctors were able to estimate the weights of patients to within 10% of measured weight (Menon 2005).

Maternal estimates are somewhat better than that of health care workers. A recent study out of Israel showed that mothers were able to estimate weight to within 5% of measured weight 73% of the time. Of note, fathers could only achieve similar results 40% of the time, which is comparable to the performance of doctors. (Goldman *et al* 1999)

In 2007 Krieser et al (Krieser et al 2007) compared four commonly available weight estimation techniques (the Broselow® Tape, APLS, Argall, and Best Guess formulae) against parental weight estimates. Parental estimates were accurate to within 10% of measured weights in 78% of cases. This was proven more accurate than any of the other methods. However this study took place in a major urban ED in Australia: it is likely that parents in this environment have better access to primary health care and more regular weight and growth measurements than their counterparts in South Africa, and therefore the applicability of the results to our setting are questionable. Local parents may find it much harder to predict their child's weight accurately.

Even allowing for accurate parental estimations (which may not be the case locally), parents are not always available during resuscitations or may not be in any psychological condition to provide useful information. In the absence of a parent or caregiver, doctors may need to rely on other clues to aid in weight estimation. A helpful local resource is the child's Road to Health Card (the local clinic card), which will show immunisations, growth trends and last measured weight.

Given the data showing how poor healthcare providers are with these estimations, the question then arises: *why* do clinicians make such poor estimations of weight, given that much of their work involves treating children whose weight and age are often recorded for them?

Many reasons are suggested, including lack of experience, individual perception, and cultural expectations of children's size (Harris 1999, Kun 2000). In resuscitation situations clinicians are often distracted and more focused on clinical interventions. Patients are supine and interacting poorly – this means a lack of visual or intellectual cues when assessing size and age.

1.2 PRESCRIBING ERRORS IN PAEDIATRIC CARE

The rate of physician related medication errors associated with managing children in the ED is generally high. Kozer and colleagues (2002) undertook a retrospective chart review and showed that the incidence of medication errors in their tertiary paediatric ED was 10%: the majority of these were dosage errors. Given the methodology and the short duration of the study (12 days), the authors suggest that in reality the rates may be even higher. With acutely ill or injured children, the potential for error increases. One American study showed a physician-related error rate of 12% in 177 critically ill or injured children; 16% of these errors were considered significant enough to cause harm, and the majority of these were preventable (Marcin 2007).

It is impossible to consider eliminating all errors from the practice of medicine; occasional errors will occur because human fallibility cannot be completely eliminated. The paediatric population is at higher risk of medication errors: this is in part due to their inherent characteristics and their precise dosing requirements, which often need calculation on the part of the clinician. Children are three times more likely than adults to suffer an adverse event related to a medication error (Levine 2001). Changing physiological and pharmacokinetic parameters at different stages of the child's development may be responsible for the increased risk. Smaller children, particularly neonates, have more limited internal reserves and are less able to cope with small changes in drug doses (Kaushal 2001).

The formulation of drug dosages by drug companies is often done by extrapolating from adult pharmacokinetic parameters. There are few clinical studies and little biological or pharmacological data on bioavailability, concentration etc; available on paediatric populations. The variability in drug metabolism and patient physiology makes adverse events more likely and predicting them impossible.

In paediatric populations, medication dosages are individualised – based on factors such as age, weight, length, body surface area and clinical condition. Whatever the choice of parameter, this calculation of dose that has to be done for every patient and every medication is a potential source for error.

Not all errors are human-related. In their commentary in Pediatrics, Goldman and Kaushal (2002) suggest that latent system problems may be responsible for the majority of human error. Health Systems related issues such as staffing, workload, medication availability and medication ordering systems may contribute in multiple different ways.

Typical problems related to paediatric medication errors include:

- Lack of formularies or reference tables for paediatric medication dosing. These are often not available in EDs.
- Lack of clear labelling of paediatric medication including dose, safety, efficacy and clinical use
- Lack of awareness of potential errors by clinical staff

- Lack of knowledge with regards to doses of drugs
- Lack of support staff such as pharmacists on site
- Lack of training in ways to avoid error
- Lack of protocols or system checks in place to identify and report errors

In developed countries where there is growing pressure to eliminate error and thus medico-legal exposure, paediatric weight estimation has been highlighted as a vulnerable area of clinical practice. Many hospitals have protocols in place such as Tape based tools and weight charts to make this process simpler and avoid litigation.

In order to reduce medication errors and ensure patient safety, there are standard practices recommended by organizations such as the FDA (the US Food and Drug Administration) and the Institute for Safe Medication Practices (Levine 2001). These practices include:

1. Increasing awareness of the potential for error through educational programs focused at all clinical staff
2. A series of system checks. These are multiple points where potential errors could be discovered and corrected.
    a. weight estimation check
    b. dose per kilogram check
    c. calculation check
    d. medication measurement check
    e. medication administration check

These are safety checks done during clinical practice usually by other healthcare providers, including professional nurses and pharmacists.

3. Computerised medication ordering systems allowing for accurate documentation and automatic safety checks.
4. Error reporting and quality improvement feedback.
5. Reducing staff workload and improving the working environment allowing for less decline in cognitive function due to fatigue or anxiety

Particularly in the USA, many of these strategies have been regulated by law. In the management of critically ill or injured children some of these systems may not be practical. Time constraints may prevent the checking of doses or calculations. The highly stressful environment increases the potential for human error; verbal drug ordering and lack of documentation means extra care has to be taken to administer the right drug in the right dose.

In South Africa there are no widespread safety protocols in place. We are also more vulnerable to error. High patient volumes, large numbers of very sick or injured children, low staffing levels and limited resources already increase anxiety and work-related stress. Many units are staffed by junior doctors who have much responsibility but little clinical supervision.

In the absence of system protocols for error reduction, the onus is on the physician to be aware of the potential for error and institute checks to minimise these.

1.3 WEIGHT AND CLINICAL ERRORS

A resuscitation, and in particularly a paediatric resuscitation, is a highly stressful situation with increased cognitive load placed upon the physician. Errors are common and constant vigilance is needed to reduce these. Incorrect weight estimation based on inappropriate estimates of age or incorrect calculations may lead to under- or overdosing of medications or inappropriate interventions.

The dosages of drugs as recommended by the International Liason Committee on Resuscitation (ILCOR) 2005 guidelines for the management of cardiac arrest situations in chidren (ILCOR 2005) are:

- Adrenaline 10 mcg/kg IV (0.1 ml/kg of 1:10 000 solution)
- Atropine 20 mcg/kg IV (0.02mg/kg)
- Amiodarone 5mg/kg IV

For peri-arrest situations (unstable tachycardias and bradycardias), other drugs to be considered or used if particularly indicated:

- Adenosine 0.1mg/kg first dose and 0.2mg/kg second dose
- Magnesium 25-50 mg/kg IV
- Lignocaine 0.5-1mg/kg IV loading dose

More details are provided in Appendix A.

In giving all of these drugs (and others) it is essential to know that we are giving them in optimal doses so as to have the desired clinical effect. A margin of safety is also required so that we do not cause toxicity. This is particularly important in drugs with a narrow therapeutic - toxic window. By convention, drug dosages are calculated per kilogram body weight. While this is easy to calculate, it may not be the most physiological: pharmacological studies suggest that Body Surface Area (BSA) may be a better way to calculate optimal drug dosage. In practice this is extremely hard to calculate, requires accurate height and weight measurements, and is time consuming. To develop the ideal dose we have to consider the pharmacokinetics of the drug: more lipophillic drugs will have larger volumes of distribution, and so in fatter children the drug will be distributed widely and more drug is needed for clinical efficacy. For lipophillic drugs actual body weight is important to determine drug dose.

Hydrophillic drugs tend to stay mainly in the plasma and are not widely distributed. The main determinant for the dose of these drugs is lean body mass: length typically is the best predictor of lean body mass (Diekmann 2007) but an average weight for age might reflect lean mass in instances where measuring equipment is not available.

In terms of the commonly used resuscitation drugs: Amiodarone is highly lipophillic and actual weight may be best to calculate dose. Adrenaline and phenytoin are hydrophilic and lean body weight or length would be best. However, lean body weight and actual body weight are not the only predictors of drug effect in vivo. Many other patient factors (pharmacokinetic) affect drugs such as age, pH, perfusion and nutritional status. While all of this may be intellectually interesting, in clinical practice our primary concern is the patient's response to therapy. For simplicity and clinical ease, estimates of body weight are typically used.

Resuscitation is not the only area of paediatric practice where accurate weight estimation and accurate drug dosing is important. Paediatric analgesia, burn management, blood transfusions and antibiotic administration all require calculation of drug dosages by weight. Incorrect weight estimation may magnify interventions and the complications associated with them. For interventions such as blood transfusion where there is already a high inherent risk, this may be compounded by dose errors. There is much debate about the appropriate formula for the calculation of blood volume for transfusion (Davies et al 2007). The standard accepted formula is:

Blood Volume = weight in kg x (desired Hb Increase) x Transfusion Factor*

*Transfusion factor = 3 or 4 by convention (although newer studies suggest that 3/ Hct may result in a more predictable Hb rise (Davies 2007))

Regardless of the Transfusion Factor, the calculation relies on accurate weight for its clinical accuracy.

Recent discussion has focused on the adequacy of paediatric analgesia in the ED, where delivery of appropriate and adequate analgesia for children is generally poor. Analgesic doses are often described as dose per weight or dose per age. European studies suggest that if medication is calculated by age there tends to be under-dosing due to incorrect weight estimates (Donald 2007). Accurate weight estimation would allow for better weight related dosing of analgesics which in turn leads to more comfortable and pain free children in the ED.

The management of children with Burns is also influenced by weight estimation (Cubison 2005). It is often difficult to weigh children with massive burns when they first present. However, inaccurate weight estimates may affect clinical management as weight forms part of formulaic burn therapy. The Parkland formula is still generally used to calculate fluid administration for the first 24 hours post burn injury.

FLUID = 4 x weight (kg) x % BSA burned

(BSA = body surface area)

Incorrect weight estimation may magnify interventions delivered. With increasing burn percentage this volume discrepancy caused by incorrect weight increases and is likely to be clinically significant. For example, for a 10 year old with a 75% burn, a 10 kg weight underestimation would equal 3000ml less IV fluid over the first 24 hours:

4 x *28* x 75 = **8.4** L vs 4 x *18* x 75 = **5.4** L

1.4 WEIGHT ESTIMATION METHODS

There is no standardised accepted means of weight estimation in South African EDs. Many units do not have bed or trolley scales for use with supine patients; in these cases, alternative methods of weight estimation need to be used.

There are many methods of weight estimation published in the literature. These include formulae based on age or length based tables and tapes. Physician training is often the only factor involved in choosing between formulae as none have previously been validated in our population. Diekmann suggests in his editorial in *Emergency Medicine Australasia* (2007) that the ideal formula for estimating weight should be one that is:

- easy to remember
- easy to calculate (particularly in stressful situations)
- able to provide a reasonable weight estimate to deliver clinically appropriate effects – so as not to under- or over-resuscitate

- accurate for both sexes
- accurate across different age-groups
- accurate across different ethnic groups
- validated for the local population

The difficulties in defining this formula have led to multiple different strategies.

The oldest and most commonly used formulae are based on age to weight ratios. These are simple to use, requiring nothing from the health care worker other than to remember the formula and undertake a simple calculation. They can be used in any environment and do not require resources.

Other formulae may be derived from length, body habitus, shoe size or a combination of these methods. There are even methods based on hanging leg weight (Haftel 1990). These methods often involve physical resources such as measuring tapes or tables, and require either a measurement or an assessment from the health care worker. This assessment may be time-consuming which would negatively impact on resuscitations.

The accuracies of the different formulae vary in terms of the populations they were developed in. They are often geographically or ethnic specific. The parameters used to estimate weight may also vary in their appropriateness and not be consistent over all ages.

1.4.1 Age-to-Weight formulae

Age-to-Weight formulae are most commonly used (Carrol 2001). These include APLS, Best Guess and Luscombe and Owens. They are based on the relationship between age (in completed years) and weight. Age-based formulae do not require any resources such as measuring tools or tables, and can be used in all environments. They require easily obtainable information, and minimal training. Their use allows for preplanning when an ED is informed of a critically ill child's imminent arrival: preparation of essential equipment and drugs can be done in advance by using commonly provided information.

One of the main problems with age-based formulae is the variation in size of different sexes at different ages, related to the timing of the onset of the growth spurt. The effect of this is that in older children there is a wider spread of weights. Earlier pubertal onset in modern populations (predominantly in girls) may also emphasise the variability between the sexes: in the older age group of children, females tend to be heavier than males (Olds 2001).

Ethnicity may also impact age-based formulae in certain populations. An attempted validation of the Broselow® Tape in Maori and South Sea Islander children showed the population is large for age and that none of the commonly used weight estimation tools apply. In this population an ethnic specific new weight tool needed to be developed (Theron 2005).

South Asian populations are generally smaller in stature and Varghese and colleagues (2006) found that the APLS formula tends to overestimate weight in these populations, particularly in older age groups.

Nutritional status as it affects growth is not considered in age-to-weight based tools. Particularly in developing countries (where malnutrition is initially detected in weight-for-age data) this may impact on age based formulae earlier. Later, when the long-term effects of malnutrition on growth present as decreased length-for-age, other length based methods will be affected.

The rising obesity epidemic with increasing weight-for-age in children – mostly in developed countries – has an impact on the usefulness of age-to-weight formulae (Olds 2001).

a) APLS formula

The **APLS** formula is taught in APLS courses around the world, and is the most widely used weight estimation method (ALSG 2005). APLS is taught in many countries including the UK, Australia, New Zealand and South Africa. The formula is:

$$\textbf{weight } \textbf{\textit{(kg)}} = \textbf{(Age + 4) x 2}$$

The use of this formula is limited to children 1- 10 years of age.

Its advantages are that it is a single formula for all children in this age range, is simple to remember, and does not require any tools such as measuring instruments and tables. This formula was initially derived from National Centre for Health Statistics (NCHS) population data from 1977 in the United States. Details of the NCHS growth charts are provided at Appendix B. There is little known about the origin and methodology used to derive the formula. In 1977 the NCHS released their growth charts: these were the first comprehensive analysis of the heights and weights of children done in the world, and were based on the NHANES I – the first National Health and Nutrition Examination

Survey. From 1971 to 1975, 33 000 people in the USA were surveyed. These growth charts remained the international standard until recently.

In 2000 the Centre for Disease Control (CDC) released its new child health data and growth charts for children 0-19 years. Data were derived from two surveys: NHANES II (which took place from 1976 to 1980) and NHANES III (1988 to 1994). It was a stronger study in that it incorporated multiple centres and a wider cross-section of the population, but is still limited by the age of the primary data. As expected these new population charts highlighted the general increase in weight and height of children in the US compared to the 1977 charts.

Ogden *et al* showed that on average 10 year old girls had increased in weight by 6.2 kg and increased in height by 3 cm in the time between the original NCHS and the 2000 CDC chart publications (Ogden *et al* 2002).

It is not only in the US that children's size is increasing. Other developed countries such as Britain and Australia have shown secular trends of increasing weight and height (Rudolph 2000). In the 1977 NCHS chart, 5% of all children were overweight (classified as > 95^{th} centile Body Mass index (BMI)). The CDC in 2000 showed that 10.3% of children between 2 and 5 years, and 16% of 6 to 9 year olds in the USA were overweight (Ogden 2002). Recent literature suggests that these numbers may even be higher now. There is also growing concern about the rapid rise in the number of overweight and obese children in the developing world.

Freedman et al (2006) analysed racial and ethnic differences in the secular trends of height, weight and BMI in children. They found that racial and ethnic differences are often attenuated by environmental and social factors such as a high calorie diet and a sedentary lifestyle.

These new height and weight standards result in inaccuracy of traditional age based formulae derived from the original charts. However, even the new charts are based on data as old as 1994, and so the population figures may well have increased even further. The APLS formula is thought by many to be dated and no longer appropriate for developed nations.

Studies from the US and the UK show that the APLS formula underestimates children's weight by up to 20% (Luscombe and Owens 2007). Black (2002) and Argall (2003) both showed moderate weight underestimation in British children with the APLS formula. This tendency to underestimate weight increases with increasing age. Thompson (2007) looked at the APLS formula in a validation study for the Best Guess method. In comparing 1843 Australian children she found that APLS underestimates weight by 12% in the preschool category (1-4 years) and by 19.9% in the school aged group (5-14 years). Although the APLS formula was used outside its prescribed limits of 1-10 years, the weight difference was still significant enough to overcome any methodology problems.

However in the developing world, where population size has not increased as dramatically, the APLS formula may still be valid. Although Varghese did show a slight tendency to underestimation in the Indian population, there was still good statistical correlation (r=0.902) between measured and estimated weights with the APLS formula (2006).

It is essential to know ones population when applying any weight estimation method. In Malawi, undernutrition is still prevalent: the national statistics office estimates that 48% of children under 5 years have stunted growth and 22% are undernourished, but 95% of them are still of an appropriate length for their age (Pollock 2007). A limited validation exercise of 148 children showed that the APLS formula overestimates weight by 10% across all age groups in this undernourished group.

b) Luscombe and Owens weight formula

Luscombe and Owens developed a new formula specifically for the UK in 2007. They reviewed 17000 children presenting to the ED at Queen Mary's Hospital, Nottingham between June and December 2005. Their premise was that the APLS formula underestimates weight in developed populations, and that a new age based formula was required. They found that the APLS formula consistently underestimated the weight of these children. The difference was 18.8% overall but was more pronounced in the older age groups. Through linear regression analysis of the relationship between measured weight and age they were able to derive a new formula:

Weight *(kg)* **= 3 x (Age) + 7**

This formula was developed for children aged 1- 10 years. As with other formulae, it was simplified to allow for ease of remembering and to allow for mental arithmetic.

While the large study population size is an advantage, the study was limited to one city and so it is uncertain if this would be representative of all UK children, or indeed children in our setting. One of the weaknesses noted by the authors was that ethnic heritage was only noted in 40% of cases and that they could not guarantee a good cross-section of ethnic groups.

An unpublished study of 301 children in a paediatric Outpatient department in Sheffield, UK independently produced the same formula through linear regression analysis of ages and weights (Mushtaq 2007). A prospective validation of this formula in a multicentre environment or a number of other countries is needed. At the moment its use appears limited to the UK.

c) Best Guess Formula

Australian researchers have also derived a local formula via regression analysis. Documented increases in the weights and heights of Australian children with the subsequent underestimation of weight by the APLS formula led researchers to develop their own formula (Olds 2001). It was estimated that children's height increased by 1cm per decade and their mass by 1kg per decade.

Researchers used a sample of 70 000 children who presented to the ED of a Paediatric teaching Hospital in Brisbane, Australia from July 2001 to June 2004. Data were used to develop three new weight prediction formulae by regression analysis. It was decided that in order to be more accurate, separate formulae would be developed in age category to correspond to the different growth velocities at different ages (Tinning 2007).

Infants < 12 months: **Weight *(kg)* = (Age in months + 9) / 2**
Children 1-4 years: **Weight *(kg)* = 2 x (Age) + 5**
Children 5-14 years: **Weight *(kg)* = 4 x (Age)**

Researchers also developed reference tables for age, sex and mean height. The aim of these was to provide a range of potential weights and allow for preparation of resuscitation drugs and equipment when a prehospital alert is received.

A retrospective review of 1800 critically ill or injured patients at the same hospital was done to validate the formula (Thompson 2007). It showed the correlation between measured and predicted weights to within 20% to occur in 76 % of infants, 83% of 1-5 year olds and 60% of 5-14 year olds.

A small independent prospective study in a different centre in Australia also showed a moderate correlation between measured weight and that calculated by the formulae. A total of 410 children seen in the ED of Sunshine Hospital in Melbourne were evaluated; they showed that the formula was accurate to within 20% in greater than 75% of children aged 1 to 5 years, and greater than 64% in children aged 5 to 11 years (Kelly 2007). Only children up to 11 years were included because that reflected the hospital's ED population. A particular strength of this study was that the population of Melbourne is more ethnically diverse than that of Brisbane where the formula originated.

A 20% standard deviation which was used as a marker of correlation is questionable. It allows for a significant variance of weight and a large margin for error when using it to calculate clinical interventions. Furthermore, all of these validation studies were done in single centres in Australia and again the potential of the formulas use in other countries is questionable. Finally, a practical issue in trying to implement the Best Guess method would be the difficulty in remembering three formulae instead of one.

1.4.2 Other Weight-to- Age formulae

There are many other formulae which have all found favour at one time or another. Most are not well known beyond the medical literature.

a) Argall's modified formula

The formula is:

$$Weight = (Age + 2) \times 3$$

This was the subject of much interest in 2003: it was the first new formula derived to try and deal with the problem of a population of increasingly heavier children. It was derived from logistical regression of pooled weights of 300 British children and was the side product of a comparison study evaluating APLS and the Broselow® Tape (which found them both to underestimate the weight of children) (Argall 2003).

A prospective validation in an Australian population showed a mean underestimation of 1.66kg. Weight estimation to within 10% of measured weight only occurred in 36% of cases (Nguyen 2006). In Varghese's comparison of weight estimation methods in the Indian population (2006), Argalls formula tended to overestimate weight by a mean of 2-3kg.

b) Nelson's formula

Nelson's formula was first described in Nelson Textbook of Paediatrics, the "bible" of paediatric education (Behrmann 2004).

Weight = *(Age x 2) + 8*	for children 1-6 years
Weight = (Age x 7) – 5	for children 7-12 years

It is not commonly used and has never been formally validated. Varghese (2006) showed that Nelsons formula correlates poorly with the actual weights in the Indian population: the formula tended to overestimate weights by up to 5 kg, particularly in the older age groups.

1.5 LENGTH BASED FORMULAE

Much of the research has moved to length-to-weight formulae. The advantage of such formulae is that there is less variation with body habitus; they are thought to be more accurate and may show less variability with age (Carrol 2001). However, they do rely on physical measurement which needs to be accurate, often involving training and needing accurate measuring tools. Measurement can also be time-consuming in emergency situations.

1.5.1 Broselow tape

The Broselow - Luten ® tape was developed in the early 1980s by Dr Jim Broselow, an Emergency Physician, as a resuscitation aid. It is a colour coded tape which is placed next to the patient. The child is measured from head to toe, and by length is assigned to specific weight class. The usefulness of the tape extends beyond weight estimation, as the colour coded weight classes also list dosages of commonly used resuscitation drugs and the sizes of resuscitation equipment such as endotracheal tubes and suction catheters. The Broselow system consists of pre-packaged colour coded drugs and equipment for simplified resuscitation. More detail on this system is provided in Appendix C.

Its use is limited to children under 35kgs or 145 cm. Children taller than this are treated as adults with the appropriate drugs and equipment. The Broselow tape was also derived from the 1977 NCHS data, meaning that it may not be as accurate in 2008.

At the time of development, the tape was thought to be the most accurate weight estimation technique in both the developed and the developing worlds.

In 1988 Lubitz showed that the tape predicted weight and interventions to within 15% in 79% of children (Lubitz 1988). However, given the changes in size in the developed world population in the 20 years since its introduction, there is a recent tendency to underestimate weight and thus resuscitation interventions. A recent prospective evaluation showed statistical weight correlation between measured and predicted weights but noted that the Broselow tape underestimated weight by 10% in all age groups (Du Bois et al 2007). In a cross-sectional study of 7500 American school children in 2003, Nieman showed a 55-60% correlation between Broselow weights and measured weights with a trend towards underestimation (Nieman 2006).

In the developing world there is still good correlation with measured weights. In India it was proven to be the most effective method of weight estimation with a very high correlation coefficient (r=0.974). In this study, however, it was noted that the tape tended to underestimate the size of the endotracheal tube required (Varghese *et al* 2006). In Hong Kong, Kun (Kun 2000) found a good statistical correlation with measured weight between 10 and 25kg, but above 25kg the tape tended to underestimate.

Technical problems exist with the usage of the Broselow tape: training is required to use it correctly; accurate positioning of the tape is required in relation to the child (with the red end at the head); accurate measurement of length and accurate interpretation of results in terms of correct colour coded block are required for effectiveness. Training in the correct usage of the tape now forms part of APLS courses, and specialised workshops exist to teach health care workers.

In South Africa few EDs have Broselow tapes, and even where they are available staff are generally not trained to use them. As the complete colour coded system of drugs and equipment is expensive to buy and maintain, it is not commonly seen in South African EDs.

1.5.2 Length-based Tools

There are lesser known length-to-weight systems.

a) IMCI

Integrated Management of Childhood Illnesses (IMCI) is a strategy developed by the World Health Organisation's Division of Child Health and Development and UNICEF (WHO 2006). It has been introduced in more than 30 developing nations around the world, and is aimed at decreasing morbidity and mortality in children under five years. The strategy focuses on the general wellbeing of the child, rather than on a single disease or condition. It provides a manual of basic paediatric care in resource poor situations in the developing world

The WHO has developed weight estimation charts as part of its IMCI system. These charts are designed primarily for nutritional assessment of the child. They were originally developed as part of the WHO growth charts released in 2005, and they plot height, weight and BMI from birth to 5 years. Data for the development of the chart was collected in 7 countries around the world and includes both developing and developed nations. This makes it much more universally applicable than the USA based charts.

The IMCI growth charts consist of a seven page document which includes weight-for-age tables and charts, and length-to-weight charts. These charts are available on the WHO website or as part of the IMCI handbook (see Appendix C). Unfortunately, the tables are long and complex; they would be a difficult resource to use in a resuscitation situation.

Although the IMCI system has been incorporated into the Primary Health Care program for children in South Africa, the height-weight and weight-for-age charts are not in general use.

b) Malawi tape

An innovative group of Paediatricians in **Malawi** have recently published their experience of creating their own local version of the Broselow tape (Molyneux 1999).

They evaluated heights and weights in their population and then developed a tape and chart with appropriate locally applicable drug dosages and interventions.

This type of instrument would be a very useful tool to develop locally.

c) Devised Weight Estimation Method

The **Devised Weight Estimation Method (DWEM)** is based on height and body habitus. It involves length measurement, and assessment of body habitus and gender. It is the only technique of weight estimation that has subjective clinician input, in that an assessment of body size (small, medium or large) needs to be undertaken. While this may help accuracy by taking to account the variations in size, the subjectivity of the assessment may increase the potential for error.

The actual method of assessment involves sex-specific length-height tables; it is too bulky a tool to use during a resuscitation situation. It is only valid for children measuring between 50 and 175cm.

The DWEM has been shown to be reasonably accurate in an American study, although it tended to underestimate weight in the children with weights above 20kg (Black 2002).

1.6 SOUTH AFRICAN CHILDREN

There are great difficulties involved in determining the appropriate formula for the South African population. The different formulae were devised and validated in developed world populations; the differences between developed world populations, whose children are increasing in size, and their counterparts in the developing world (where malnutrition is still a very real problem), make it difficult to find a universal weight estimation tool.

In developed countries there has been an increase in the weights and heights of children over the last 20 years: the impact of better nutrition and better healthcare on this may be held to be a positive one, but westernised diets and a sedentary lifestyle has increased the rates of childhood obesity (Olds 2001). Earlier pubertal onset also results in greater weight variation (Olds 2001). On the other hand, the South African population is a diverse one. We have a multitude of ethnic backgrounds and a vast range of socio-economic situations. We have both developed world and developing world challenges, and have populations which are representative of both.

Although there is much debate as to which growth charts are applicable to our environment, the 2000 CDC charts are currently used as our reference standard (Pettifor 2000).

There is a paucity of local data on children's weights and growth patterns. The Health of the Nation study (Armstrong 2006) suggested a trend to obesity and overweight in all population groups, similar to that of the developed world 10 years ago. The study found that 14 % of boys and 17.9% of girls between 6 and 13 years were overweight (>95th centile BMI). However, in low socio-economic and rural environments growth stunting and undernutrition is still a problem. WHO data from 2000 for South Africa estimates the rate of stunting in children under 5 years at 30.9%, and the Underweight-for-Age rate at 9.3% (WHO 2006). However Wallis (2006) found similar heights and weights in our population as UK children.

The Western Cape population may trend more towards that of developed nations, as most of the provinces' population is urbanised and the area is more affluent the much of the country. Healthcare delivery is better, and employment rates are higher when compared to the rest of the country. Life expectancy at birth is the highest in the country (StatsSA 2007). A large proportion of the population has a lifestyle similar to that in the developed world, with comparable growth patterns (Armstrong 2006). But particularly in rural areas malnutrition does occur and a significant number of children are stunted.

There has been no work previously on which weight estimation tool is appropriate in our population. Given the conflicting factors influencing children's weight and the multiethnic nature of our population, it is hard to predict if the traditional formulae hold true in South Africa.

CHAPTER 2: AIM

The aim of this study is to determine the most accurate and clinically applicable weight estimation formula for children in South Africa.

In order to achieve this aim, the following objectives are necessary:

1. To perform a literature review of the available weight estimation methods and their accuracy
2. To find a database of South African children
3. To compare estimated weights derived from different methods with measured weights in our population
4. To evaluate the clinical efficacy of emergency interventions derived from different formulae
5. To evaluate the potential for error inherent in the different weight estimation methods
6. To evaluate the problems associated with using weight estimation formulae
7. To describe the inherent characteristics of our local population of children

CHAPTER 3: LITERATURE REVIEW

The literature review for this study took the form of a search of the following databases:

- **Medline 1966 – present**
- **Pre-Medline**
- **EMBASE 1982 - present**
- **OVID**
- **Google scholar**

The followings search terms were used:

For review of weight estimation: *paediatric* + *weight* + *estimation* + *children*

For evaluation of error reduction and quality of care: *children* + *medication* + *safety* + *error*

All retrieved items were assessed for suitability, by a review of the abstract. All articles that were included had their reference lists checked for more articles of interest.

Attempts were made to contact prominent authors in the field, as identified from key publications.

An attempt was made to obtain previously unpublished materials including dissertations and clinical trials via internet registries.

A total of **94** articles were retrieved, of which **60** were deemed useful, further articles were identified through the methods detailed above. Contact with authors was only helpful in one case.

CHAPTER 4: METHODOLOGY

Age, Height and Weight data were analysed from an existing database. These data had been gathered for a doctoral cross-sectional study, performed at the Red Cross War Memorial Children's Hospital in Cape Town, South Africa (Wallis L, 2006).

DATABASE

The database provided anonymous height, weight and sex data presented in a Microsoft Excel Spreadsheet. Children were entered into the database if they:

- Were aged under 13 years
- Presented within 12 hours of an acute injury.

All other children were excluded from the study.

Data were collected over a nine-month time period, from March – November 2002. The doctors and nurses in the Trauma Unit received an extensive education programme during February 2002, in which they were taught how to collect the necessary data onto the child's Trauma Unit attendance record. The educational session was repeated for new joiners at the unit, and also for all staff after a three-month period had passed.

All staff were shown a standardised method of measuring height in non-walking children with a laminated tape. For those children who were walking, medical physics fixed a laminated tape measure to a wall in the unit. Staff were taught to record weight using hospital scales that had been calibrated by the medical physics department. They were recalibrated after three and six months. For those children who were unable to stand on the scales, the ICU bed scales (also regularly calibrated) were used to determine weight on the day of attendance.

Age was rounded down to the last completed year. This was done by convention as a way to compare with other studies which all included age in years. This is also practically useful as all formula use age rounded off to make it simpler to calculate.

All information was collected by the doctorate author, either prospectively as the child came through the unit or at the latest on the day following their attendance. All data were transferred to a Microsoft Excel® spreadsheet: a random sample of 10% of entries was checked after completion of data collection to check the accuracy of data entry.

The database was chosen because weight and height measurement were standardised. Also, the Red Cross Trauma Unit is unique in Cape Town in that in sees patients from all over the city. It provides primary, secondary and tertiary level trauma care to children up to 12 years of age.

Consent for use of the database was received from the primary researcher. Security was maintained via password access.

DATA ANALYSIS

Only children between 1 and 12 years who had both weight and height data recorded were included. The validation of formulae in infants aged less than one year was not done: in this population the relationship between weight and length or age is less predictable – the primary influences in weight are gestational age, intrauterine development, breastfeeding and nutrition (Ogden 2002).

Variables were defined as:

- Age - in completed years
- Height - rounded off to nearest 1cm
- Weight - rounded off to nearest 0.1kg

In this study, length and height were used interchangeably as it was impossible to know which children were measured lying down and which were measured standing. While it is known that there is a statistically significant difference between recumbent length and stature measurements in children, this is unlikely to significantly impact the results.

Data were analysed using the STATA programme (STATA SE v.10), licenced to UCT. Assistance in statistical methods was provided by the Public Health Department at UCT.

Data were analysed for all children and with subgroup analysis for:

- males and females
- age categories:
    - 1-4 years
    - 5-10 years for APLS and Luscombe and Owens
    - 5-12 years for Best Guess and Broselow® tape

These age categories were chosen because they were previously accepted in the literature and logically divided children into preschool and school-going ages.

Mean percentage error was calculated for all formulae in the defined categories.

Correlation between measured and estimated weight was assessed by calculating *t tests* for measured weight and the weight calculated by each formula. A *p value* of <0.001 was considered significant.

Two way scatter plots were chosen to visually represent the differences between measured and estimated weights in the different formulae.

ETHICAL APPROVAL

Ethical approval for this study was obtained from UCT Ethics Committee. **REC REF 465 / 2007.**

OUTCOMES

The **Primary outcome** was to evaluate the correlation between measured weight and estimated weights as calculated from the various tools (table 1):

	Formula	Age limits (years)
APLS formula	(Age + 4) x 2	1 – 10
Luscombe & Owens	3 x Age + 7	1 – 10
Best Guess	2 x Age + 5 4 x Age	1 - 4 5 – 12 *
Broselow® Tape	As per height	Up to 145cm

Table 1. Description of formulae and limitations

**Although the Best Guess formula has been validated up to 14 years, for the purposes of comparison only children up to 12 years were included.*

The **secondary outcome** of the study was the evaluation of the differences in doses calculated by measured and estimated weights for three crucial resuscitation interventions:

- **Intravenous fluid bolus volume** - This is calculated at *20 ml/kg*. Clinicians are likely to continuously evaluate response to fluid: however, as the accepted resuscitation protocols advise blood as fluid of choice after the second fluid bolus, incorrect dosages of blood calculated with these formulae may result in overtransfusion.

- **Adrenaline dose** - this is calculated at *0.1ml/kg for 1:10000 solution*. Adrenaline is the first and most important drug given in resuscitation events. Adrenaline has inotropic, chromotropic and dromotropic effects and causes peripheral vasoconstriction. In resuscitation it increased perfusion pressure and increases the likelihood of converting Ventricular Fibrillation to a perfusing rhythm. However, in excess it may lead to tachycardia, hypertension and myocardial ischaemia.
- **First Shock Defibrillation Dose** - *2 J/ kg.* This is the recommended first dose for manual defibrillators in the 2005 international resuscitation guidelines (APLS 2005). Clinically this may be more affected by inaccurate weight estimation as there are limited low level values on defibrillators and incorrect calculations may be magnified by choosing the wrong setting. There is little evidence in humans regarding the clinical effects of higher current.

Correlation between dose calculated from measured weight and estimated by various tools will be assessed using *t tests*. This correlation was assessed overall, in different age groups and in sex categories.

Endotracheal tube (ETT) size was not included in the secondary outcomes even though it is often used in studies to validate weight tools. However, there is great difficulty in standardising the techniques used to choose ETT size. Choice is based on age, size or medical condition; or a variety of tables can be utilised. These include the Oakley table and Shan (Black 2002). Even though it is suggested that height-based tools may be better than age there is no acceptable standard for ETT size (Luten 1992).

CHAPTER 5: RESULTS

The study population was a sample of children between 1 and 12 years seen over a 9 month period in the Trauma Unit at Red Cross Hospital in 2002. A total of 3233 patients were included in the study; of these, 2053 (63.5%) were males. There was a preponderance of males to females particularly in the older age groups: 61% versus 39% in the preschool group, and 66% vs 34% in the school-going group (table 2).

	Male	**%**	**Female**	**%**	**Total**	**%**
1-4 yrs	872	61	563	39	1435	44
5-12 yrs	1181	66	617	34	1798	56
Overall	**2053**	63.5	**1180**	36.5	**3233**	**100**

Table 2 Population distribution

The graph below (figure 1) shows the spread of ages in the study. All ages are well represented with at least 190 children in each.

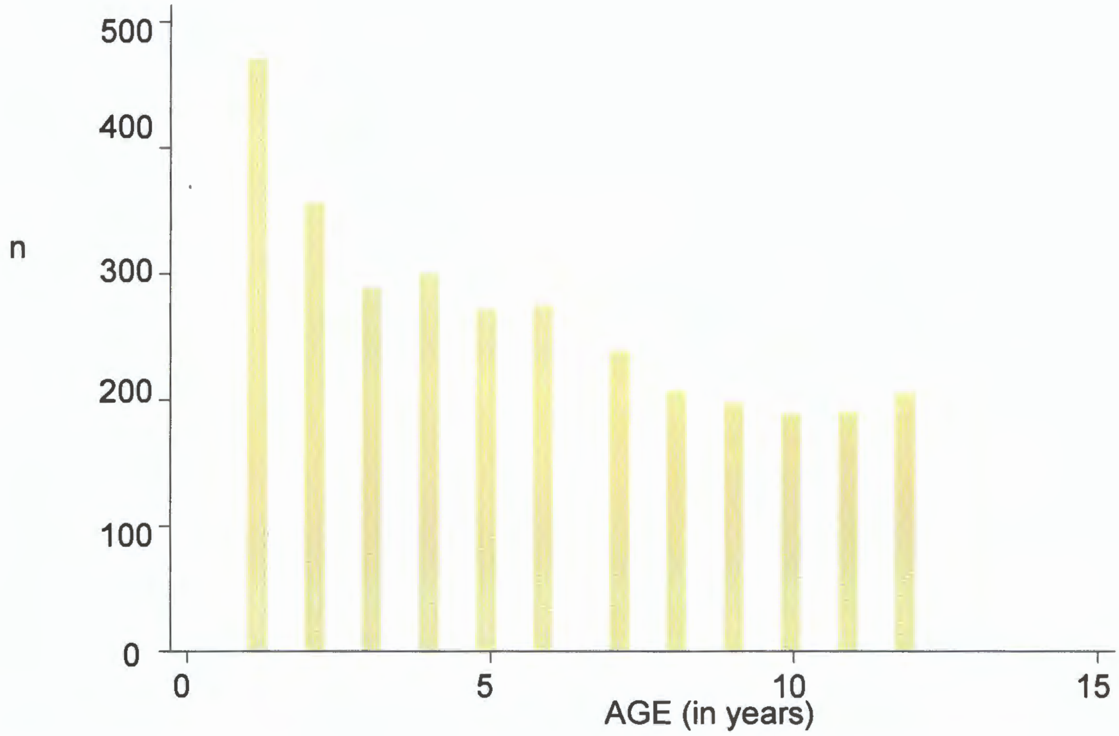

Figure 1. Age Distribution

One and Two year olds together formed 26% of the population. However the distribution tended to even out for the older age groups. The age and sex distribution with the population skewed towards the younger age groups and the male preponderance is typical of childhood trauma incidence (Burchart 1997).

Although Ethnic distribution was not taken into account in the evaluation of the weights, Wallis (2006) had described the same population as:

- Black 56%
- Coloured 30%
- Asian 8.1%
- White 3.5%
- Other 2.5%

WEIGHT AND HEIGHT

Mean measured weights for each age show little difference between males and females in the younger age groups. From the age of nine, females begin to get heavier than males as the pubertal growth spurt kicks in (table 3 & figure 2).

Age (years)	Mean weight (kg)	Mean weight Male (kg)	Mean weight Female (kg)
1	10.8	10.7	10.8
2	12.7	12.8	12.5
3	14.6	14.7	14.3
4	16.4	16.5	16.3
5	18.8	19.1	18.4
6	20.6	20.8	20.2
7	23.7	23.6	23.8
8	25.2	25.1	25.4
9	29.0	28.8	29.5
10	32.5	31.8	33.8
11	35.5	34.8	36.6
12	39.3	38.4	41.9

Table 3 Mean weights

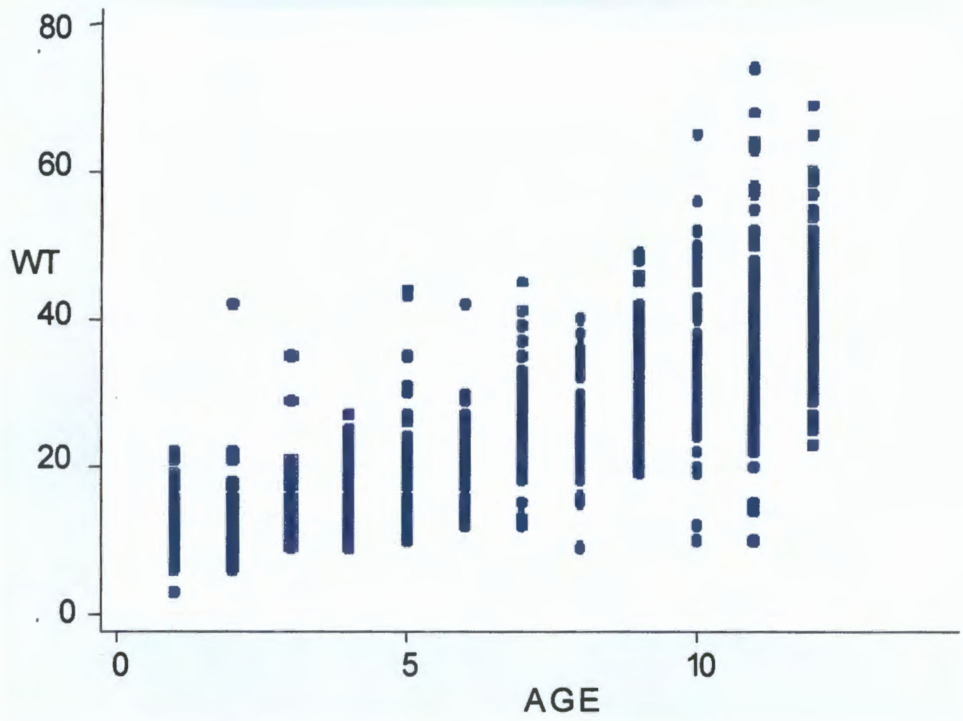

Figure 2. Weight distribution of population

Weight in kilograms is displayed on the vertical axis and age in years on the horizontal axis.

PRIMARY OUTCOMES

The relationship between measured and estimated weights calculated by the four different tools was determined by *paired t tests.* In keeping with instructions for their use, in the assessment of the both the APLS and Luscombe and Owens formulae, only children between 1 and 10 years were included; for the Best Guess formula, analysis included all children 1-12 years; for the Broselow® tape analysis all children with heights above 145cm were excluded. Results are presented in table 4.

TOTAL	Mean weight	APLS	*p value*	L&O	*p value*	BG	*p value*	BLT	*p value*
Overall	18.7	17.5	*<0.001*	21.2	*<0.001*	24.7	*<0.001*	18.9	*0.0001*
1-4 yrs	13.2	12.6	*<0.001*	13.9	*<0.001*	14.6	*<0.001*	12.7	*<0.001*
5-12 yrs	24.3	22.5*	*<0.001*	28.8*	*<0.001*	27.2	*<0.001*	24.6	*<0.001*

Table 4a. Comparison between measured weights and estimated weights

Key:

Mean weight = mean weight for 1-12 years, in kilograms
APLS = Estimated weight from APLS formula, in kilograms
L&O = Estimated weight from Luscombe and Owen formula
BG = Estimated weight from Best Guess formula
BLT = Estimated weight from Broselow ® tape
* = correlated with mean weight 1-10 years
p value = statistically **not** significant p value (good association between measured and estimated weight)

TOTAL	Mean weight	APLS	*p value*	L&O	*p value*	BG	*p value*	BLT	*p value*
Age 1	10.8	10	*<0.001*	10	*<0.001*	12	*<0.001*	10.2	*<0.001*
2	12.6	12	*<0.001*	13	*0.008*	14	*<0.001*	12.1	*<0.001*
3	14.6	14	*<0.001*	16	*0.0001*	16	*<0.001*	14.0	*<0.001*
4	16.4	16	*0.003*	19	*0.0004*	18	*<0.001*	16.0	*0.0009*
5	18.9	18	*0.0003*	22	*<0.001*	20	*<0.001*	18.3	*0.0157*
6	20.6	20	*0.0008*	25	*<0.001*	24	*<0.001*	20.3	*0.1103*
7	23.7	22	*<0.001*	28	*<0.001*	28	*<0.001*	23.2	*0.037*
8	25.2	24	*<0.001*	31	*<0.001*	32	*<0.001*	25.3	*0.47*
9	29.1	26	*<0.001*	34	*<0.001*	36	*<0.001*	28.5	*0.31*
10	32.5	28	*<0.001*	37	*<0.001*	40	*<0.001*	30.7	*0.12*
11	35.5	-	-	-	-	44	*<0.001*	30.9	*0.11*
12	39.3	-	-	-	-	48	*<0.001*	33.4	*<0.001*

Table. 4b. Comparison between measured and estimated weights for each year

The Broselow Tape shows a good statistical relationship between measured and estimated weights from 5 to 10 years of age.

Sex	Mean weight	APLS	*p value*	L&O	*p value*	BG	*p value*	BLT	*p value*
M	18.9	17.7*	*<0.001*	21.5*	*<0.001*	18.9	*<0.001*	19.4	*<0.001*
F	18.3	17.1*	*<0.001*	20.7*	*<0.001*	18.3	*<0.001*	18.5	*<0.001*

Table 4c. Comparison of measured weight vs estimated weights by sex

Mean percent error, as a measure of deviation from measured weight, was calculated for each category and results are presented in table 5.

	Mean error (%)			
	APLS	**L&O**	**BG**	**BLT**
overall	-6.4	+13.4	+17.6	-10
1-4 years	-3.8	+5.3	+10.6	-3.8
5-12 years	-7	+18.5	+20.6	-9.6
Males	-6.4	+13.8	+33.3	-2.6
Females	-6.6	+13.1	+30.6	-1

Table 5 Mean percent error for estimated weights by formulae

There is little to choose from between the APLS and the Broselow® Tape, both of which underestimate weight slightly. Luscombe and Owen and the Best Guess formula both tend to overestimate weight.

APLS formula

The APLS formula was evaluated for children 1 to 10 years (n = 2832). Although there are statistical differences, overall there is good association between measured weights and formula derived weights.

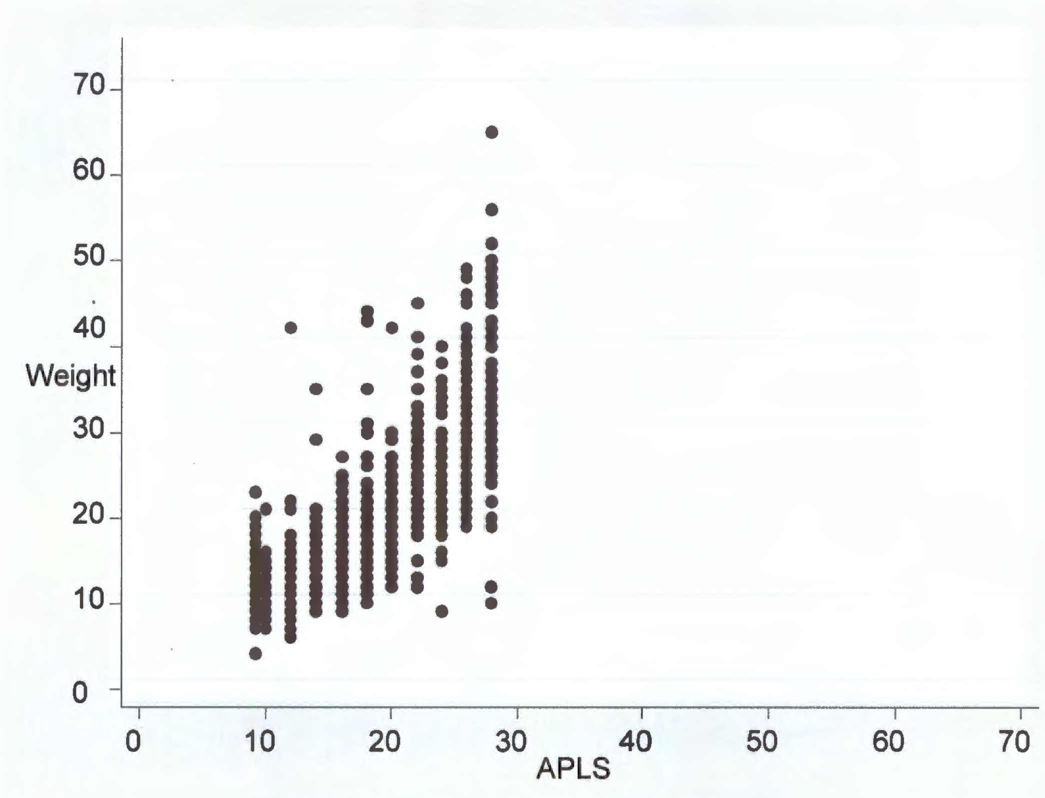

Figure 3. Scatterplot of measured weight vs APLS predicted weight

Vertical axis shows weight in kilograms and horizontal axis shows estimated weight from APLS formula in kilograms.

Both weight and height tend towards the top right of the graph indicating a positive association between APLS weight and measured weight.

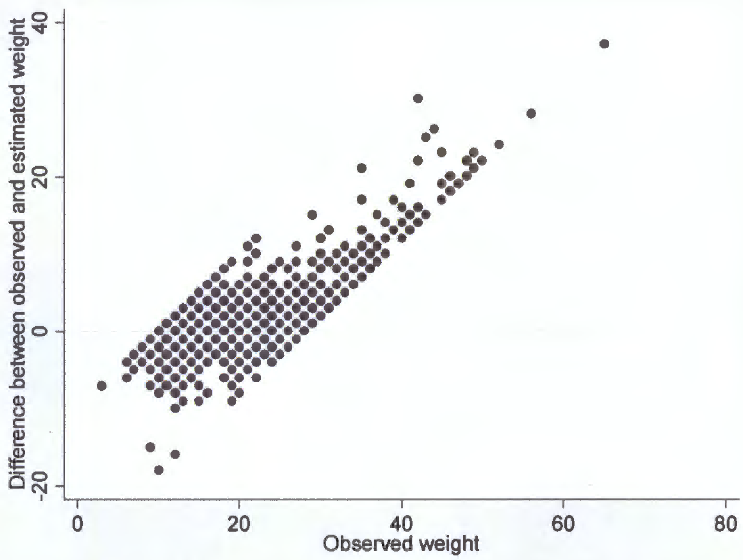

Figure 4. Bland-Altman plot of APLS to observed weight

The **APLS** formula tends to **underestimate** weight in the group 1–10 years, although this trend worsens with increasing age. In the preschool group this difference is minimal, although still statistically significant. However, by 10 years the difference is 4.5kg: 14 % below actual weight. The difference between measured weight and the APLS estimation is statistically significant overall and in both age and sex categories. The mean percent error difference is -6.4% overall (i.e. a 6.4% underestimation by the formula).

Luscombe & Owens

The Luscombe and Owens formula was evaluated for children from 1 to 10 years (n = 2832).

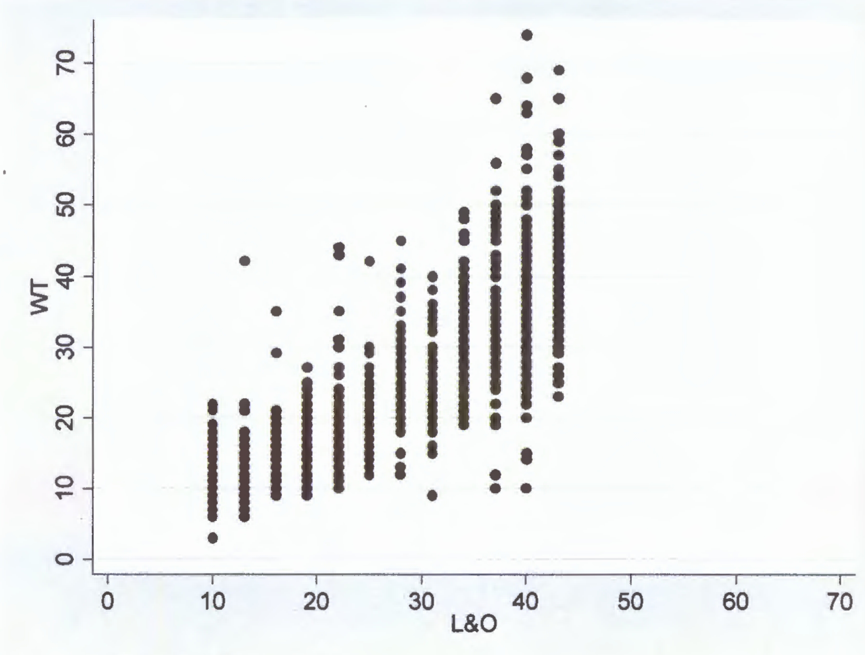

Figure 5. Scatterplot of weight vs Luscombe and Owens weight

Vertical axis represents Measured Weight in kilograms and Horizontal axis represents estimated weight from Luscombe and Owens formula.

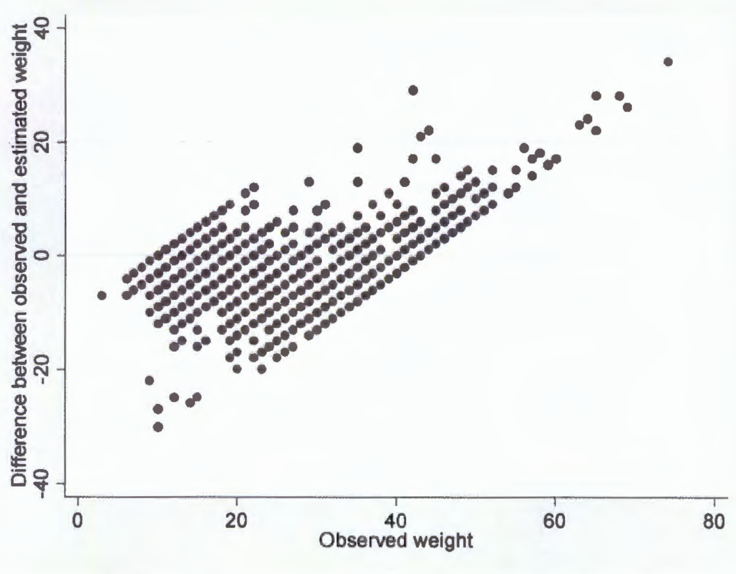

Figure 6. Bland-Altman plot of Luscombe and Owens weight to observed weight

The scatterplot shows a poor association between measured weight and weight estimated by formula.

The **Luscombe and Owens** formula tends to **overestimate** weight in the 1 to 12 year old population. The mean percentage error is 13.4%; the overestimation becomes more pronounced in older age groups. This difference is statistically significant in all categories. At age 10 the absolute weight difference is 4.5kg (a 14% weight overestimation).

Best Guess

The Best Guess formula was evaluated for children 1 to 12 years (n= 3233).

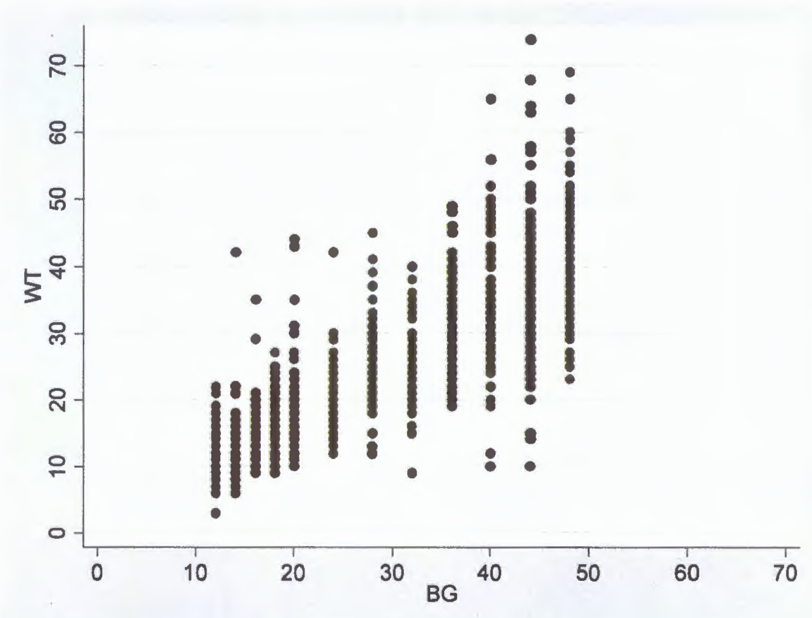

Figure 7. Scatterplot of weight vs Best Guess weight

Wt on the vertical axis represents measured weight in kilograms and BG on the horizontal axis represents estimated weight in kilograms from the Best Guess formula.

There is a poor association between measured weight and weight estimated by the Best Guess formula.

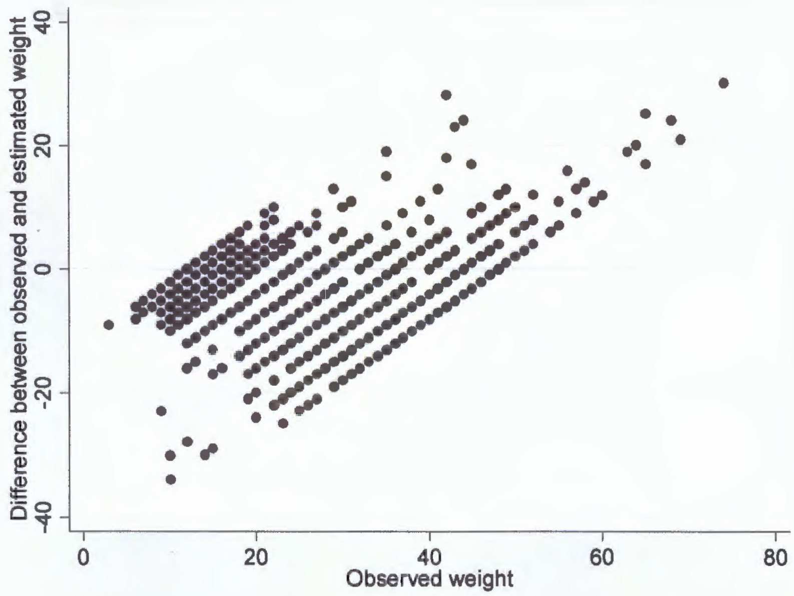

Figure 8. Bland-Altman plot of Best Guess to observed weight

The **Best Guess** formula also consistently **overestimates** weight between 1 and 12 years; this also worsens with increasing age. The *p value* is also statistically significant overall and in all subgroup analyses.

This formula showed the greatest difference between measured and expected weights: at 1 year the difference is 1.2kg (11%) and at 10 years 7.5kg (23% overestimate). The mean percent error overall is 17.6%.

Broselow Tape

The Broselow tape was evaluated for children 1 to 12 years but less than 145 cm in length (n = 2998).

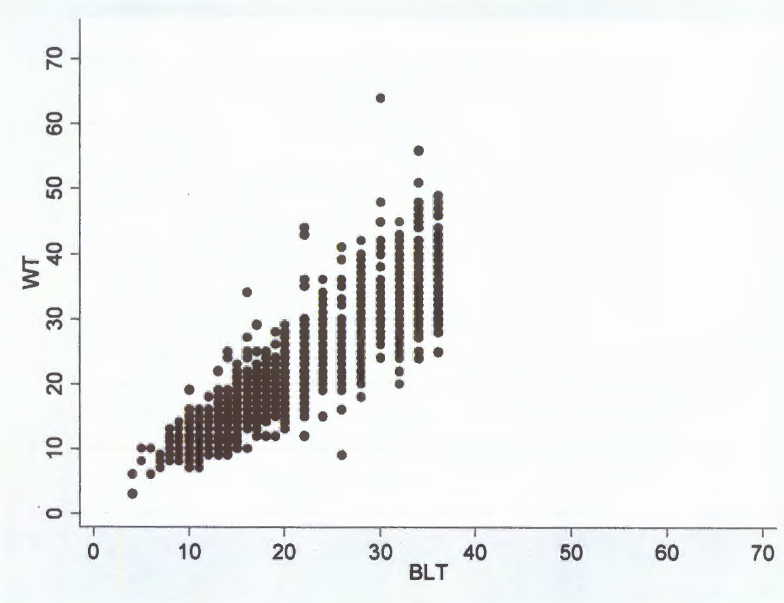

Figure 9. Scatterplot of weight vs Broselow® tape weight

The vertical axis represents measured weight in kilograms and the horizontal axis represents weight estimated from the Broselow® tape in kilograms.

The scatter plot demonstrates good positive relationship between measured weight and Broselow® tape weight.

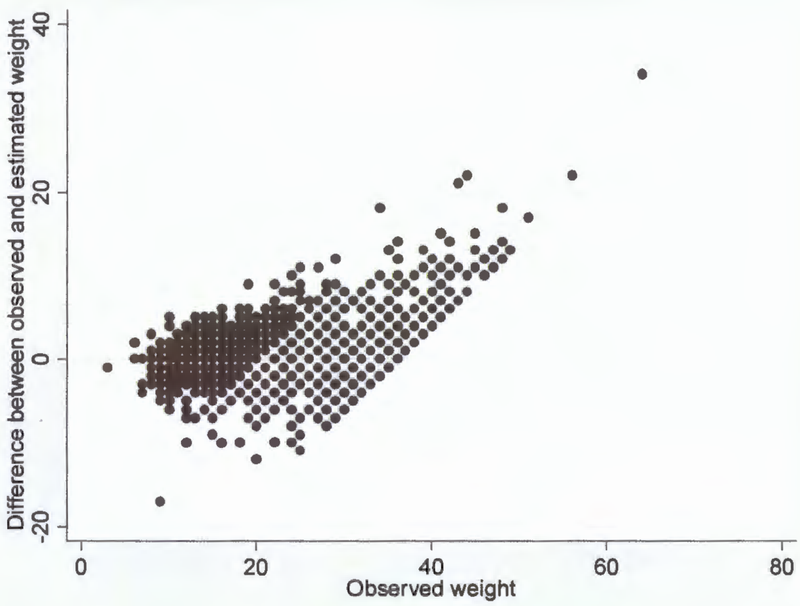

Figure 10. Bland-Altman plot of Best Guess to observed weight

The **Broselow Tape** produced a good association between measured and estimated weight. It still tends to underestimate weight and a statistical difference was shown overall and in the defined subgroups for both. However individual age analysis is favourable.

The mean percent difference was 10% overall for **BLT** and 6.4 % for **APLS**. The underestimation increases slightly with age.

SECONDARY OUTCOMES

Paired t tests were used to determine the relationship between the dose of adrenaline, resuscitation fluid bolus and defibrillation dose as determined by the measured weight and those estimated by the four different tools.

Subgroup analysis was done for both males and females, and for age groups 1-4 years and 5-12 years.

Adrenaline dose

	Mean dose	APLS	*p*	L&O	*p*	BG	*p*	BLT	*p*
overall	2.1	1.7	*<0.001*	2.1	*<0.001*	2.5	*<0.001*	1.9	*0.0001*
M	2.1	1.8	*<0.001*	2.2	*<0.001*	2.5	*<0.001*	2.0	*0.016*
F	2.1	1.7	*<0.001*	2.1	*<0.001*	2.4	*<0.001*	1.9	*0.016*
1-4 yr	1.3	1.3	*<0.001*	1.4	*<0.001*	1.5	*<0.001*	1.3	*<0.001*
5-12 yr	2.7	2.3	*<0.001*	2.9	*<0.001*	3.3	*<0.001*	2.5	*0.1503*

Table 6 Adrenaline dose (mls of 1:10 000 solution)

The **APLS** formula underestimates the adrenaline dose statistically. Both **Luscombe and Owens (L&O)** and **Best Guess** formulae overestimate the adrenaline dose: all of these differences are statistically significant. The Luscombe and Owens formula overestimates by 0.2mls (in the 5-10 yr old group Best Guess overestimates the dose by 22% and Luscombe and Owens by 21%).

The **Broselow® Tape** dosages show a statistical relationship between measured weight dosages in three subcategories, but not overall. It showed the best agreement with measured weight doses.

Fluid bolus

	Dose 1-12	APLS	*P*	L&O	*p*	BG	*p*	BLT	*p*
overall	373	350	*<0.001*	424	*<0.001*	434	*<0.001*	364	*0.0002*
M	378	354	*<0.001*	431	*<0.001*	440	*<0.001*	368	*0.011*
F	366	342	*<0.001*	414	*<0.001*	424	*<0.001*	357	*0.088*
1-4 yr	264	251	*<0.001*	277	*<0.001*	291	*<0.001*	256	*<0.001*
5-12 yr	486	450	*<0.001*	575	*<0.001*	580	*<0.001*	478	*0.88*

Table 7 Fluid Bolus in mls

The association with Fluid bolus dose follows the same pattern. The **APLS** formula statistically underestimates the dose; **L&O** and **Best Guess** formulae overestimate dose consistently, particularly in older age groups. In the 5-12 year age group L&O shows an 18% overestimation and Best Guess shows a 19% overestimation. The **Broselow® tape** shows a statistical relationship between measured weight dose, except in the 1 to 4 year age group.

	Dose (J)	APLS	*p*	L&O	*p*	dose	BG	*p*	BLT	*p*
Overall	37	35	*<0.001*	42	*<0.001*	42	50	*<0.001*	38	*<0.001*
M	38	35	*<0.001*	43	*<0.001*	43	50	*<0.001*	39	*<0.001*
F	37	34	*<0.001*	41	*<0.001*	41	48	*<0.001*	37	0.0001
1-4 yr	26	25	*<0.001*	28	*<0.001*	26	29	*<0.001*	25	*<0.001*
5-12 yr	49	45	*<0.001*	58	*<0.001*	54	66	*<0.001*	50	0.009

Table 8 Defibrillation dose in Joules

The defibrillation dose was underestimated by the **APLS** formula, with a maximum difference of 8% in the 5-12 year age group. Once again the dose is overestimated by the **L&O** and **Best Guess** formulae: the differences are 18% and 22% respectively in the 5-12 year age group. The **Broselow ® tape** demonstrates the best association.

CHAPTER 6: DISCUSSION

Although statistical differences between measured weight and estimated weights exist for all four of the age-weight estimation techniques, the true differences are small. Whether the differences are clinically significant when used by clinician who is constantly evaluating the effects of therapy is unlikely. However, in medicine we strive for accuracy and the formula which gives us the best estimate of weight and thus the best clinical efficacy is the one we would prefer to use.

6.1 STUDY LIMITATIONS

One of the limitations of this study is that the analysis was done on secondary data which is five years old. However, it is unlikely that any truly significant changes within that population occurred in the interim.

A potential measuring error may have occurred in that children were weighed partially clothed. This may have had an effect on the individual measured weights particularly in smaller children. However, the majority of the children were weighed in little more than their underwear and a light top and therefore the margin of error is likely to be small. The large sample size would also minimise error.

The study population is a convenience sample of patients who presented to the trauma unit. The population in this study was skewed towards males (63%), and one and two year olds each accounted for more than 10% of the total population. This is reflective of the peaks of childhood trauma: Medical Research Council data suggest that male children are more at risk of injury in all age groups (Butchart 1997). In the 1-4 year age group the injury rate in South Africa is 90/1000 population. In the 5-9 year age group it is 66/1000 population (Butchart 1997). In keeping with these statistics our population is male predominant with peaks in the younger age groups. This may be a different population to what is generally seen in emergency departments, particularly medical emergencies.

The effect of ethnic race was not considered in this study. African and Coloured children form the majority of the patient population, but sub-group analysis by race has not been possible. The effect of ethnicity on weight may be less than the effect of socioeconomic status in urbanised populations. The ethnic spread of the population of this study is representative of that seen in many provincial hospitals, but further work is needed on other population groups with different ethnic mix.

6.2 STUDY STRENGTHS

The referral patterns of Red Cross Hospital may counteract some of the bias gained by a single centre study. Because of its reputation and open door policy, children from all over the Western Cape and across all socio-economic categories are seen.

In terms of standardisation this study succeeds because it has one set of trained observers with a formal prescribed technique of weighing children.

Length and weight were measured in an easily reproducible fashion allowing for comparison of results. It would be technically very difficult to run this as a multicentre study because of the challenges involved in attempting to standardise measuring techniques and instruments at multiple sites. The majority of the studies of this nature have occurred in single centres where researchers were able to control the potential bias.

The study was based in an emergency department rather than an outpatient clinic. This is the environment where the weight estimation technique is likely to be used and thus reflects the population it is to be used on.

6.3 VALIDATION OF WEIGHT ESTIMATION METHODS

The APLS formula, which is easy to remember and widely used throughout the Western Cape has been proven to correlate well with measured weights in our population. There is a slight underestimation, particularly in the older age groups, but the overall difference from the mean is an underestimate of only 6.4%.

The Broselow tape also shows correlation of measured weight to estimated weight within the South African population. The mean error is an underestimate of 10%. Analysis of individual one-year age groups shows statistical correlation between mean Broselow weight and measured weights from 5-11 years. This suggests that the Broselow tape may be more accurate in this range.

Luscombe and Owens and the Best Guess formula – the new British and Australian formulae – consistently overestimate the weights of children in our population. The mean error for Luscombe and Owens is an overestimate of 13.4% and for Best Guess this is 17.6%.

As expected our population has not reached developed world standards. Whether this may still be true in a hospital that caters to a higher socio-economic group is debatable. This emphasises the constant need to review population trends and be aware of local socio-economic differences. Our population is currently lighter than their developed world counterparts but in a few years we too may outgrow the Broselow tape formula. None of these formulae should be used in isolation. It is the responsibility of the physician to use his or her clinical judgment in conjunction with any weight estimation method. The child with short stature who only fills the top quarter of the bed is unlikely to weigh 30kg, even if he is 10 years old.

6.4 Secondary Outcomes

a) ADRENALINE DOSE

The Broselow tape dose show the best association with measured dose. At low volumes the small differences are unlikely to make a clinical difference. Given that adrenaline is hydrophilic and has a small volume of distribution, there is a potential for toxicity with age based formulae that overestimate weight. If much of the increased weight in modern populations is adipose rather than lean body mass, then we may be giving too much adrenaline.

b) FLUID BOLUS

The clinical effects of inaccurate fluid bolus calculations are likely to be minimal. In practice most Emergency Physicians give the fluid in aliquots titrated to effect, rather than administering a set volume. Signs of clinical improvement such as increased Blood Pressure and urinary output are the most important clinical indicators and should guide resuscitation. Where maintenance fluid is calculated with estimated weight and the child not observed closely, this may cause harm.

Even though the differences in volume resulting from these weight errors may be substantial, children are generally well placed to tolerate any extra fluid administered. The exception may be cardiac or renal patients, but in these cases careful titration of fluid to effect is more important anyway, and should be occurring.

c) DEFIBRILLATION ENERGY

Whether the differences in defibrillation dosages, while statistically significant, impact practically is unknown. Most defibrillators available in the state healthcare setting are older models with limited low level settings anyway, resulting in under or over application of energy levels. This often results in energy dose 10 or 20J higher or lower than needed. Whether this is having a detrimental effect can be theorised but there is no available evidence to support or refute it.

The accepted dose of current (2J/kg) is derived from extrapolation from adults and is accepted by convention. The 2005 ILCOR guidelines recommend 2J/kg for the first manual defibrillation, followed by 4J/kg. The South African Resuscitation council guidelines recommend 4J/kg throughout. It is unknown whether higher currents caused by weight errors to cause harm.

There is little physiological evidence for the dose. The upper limit of current for safety and the lower limit of current that is still effective have not been determined. In paediatric models high levels of current up to 9 J/kg have been used without adverse effects (ILCOR 2005). Animal studies suggest that large energy doses cause less myocardial damage in the young heart than in the "older" heart.

6.5 CLINICAL EFFECTS OF INACCURATE WEIGHTS

Does incorrect weight estimation have an effect on morbidity and mortality in paediatric resuscitation? There is little clarity as to what dose of resuscitation drugs is ideal: much is dependent on the child's metabolism and pre-morbid state. It is logical though that the smaller the child, the more likely incorrect doses are likely to have an effect.

It has been suggested that under-resuscitation is potentially better than over-resuscitation (Anderson 2007). Physiologically, fluid and energy expenditure have been calculated from lean body mass, therefore drug dosages and fluid volumes correlate best with lean body mass. It is thought that the increase in size in populations, particularly in the developed world, is an increase in adiposity and BMI rather than an increase in height and lean body mass (Olds 2001). This means that even though the formulae calculating total body weight have changed, the body weight we should be using to estimate fluid and drugs is unchanged. For our population this means that the APLS formula would be the best choice for resuscitation drug dosage calculations.

It is unclear whether by the same token equipment sizes are related to lean body mass rather than true weight. Hofer (2002) showed a better correlation of ETT size with height rather than age. Length is a better correlated with lean body mass, but age based formulae such as ((Age +4) / 4) are still commonly used when no other resources are available (ALSG 2005). However, there appears to be much individual variation in this. Varghese showed a good correlation between Broselow tape weights and measured weights but although a range of sizes were provided, found that there was a tendency to underestimate ETT size. We would need a prospective validation of Broselow tape ETT size in this country.

6.6 LOCAL APPLICATION

Although the APLS showed a slightly better association with measured weight, the Broselow Tape showed a better statistical relationship with all the secondary outcomes – Adrenaline dose, Fluid Bolus and Defibrillation dosage. These clinical effects are probably more important than the absolute weight. The Broselow tape also has other advantages: it reduces cognitive load by calculating weight, listing appropriate sized equipment and the doses of commonly used drugs, and can be used with a system of pre-packaged equipment.

It appears that the important factor is in the consistency of use rather than the choice of weight estimation method. All of them have positive and negative aspects: it is important to decide a method of choice and educate staff to its use and limitations.

Luten and Broselow (2002) have developed the concept of cognitive load. This is the "mental burden experienced by the decision maker". It is higher when the task is less familiar or more demanding e.g. requiring calculations. The aim of the tape-based tool was to reduce the cognitive load on the physician by simplifying weight estimation, removing the need to remember drug dosages and removing the need to calculate said dosages for each patient. When using the Broselow tape the workload on all team members is reduced. Equipment of the right size and drugs of the right concentration are easily accessible.

Another way to decrease cognitive load particularly in resuscitation (where set processes occur simultaneously or nearly simultaneously) is by training. Simulation training will increase familiarity and increase the degree of automaticity of certain actions such c-spine immobilization and airway assessment. This will lead to increasing confidence in the ability to handle resuscitations and less cognitive strain during the event. Paramedics who felt uncertain about managing paediatric cases were re-evaluated after training with the Broselow; although 55% were initially hesitant, 95% proved able to deliver accurate interventions after training (Vilke 2001).

Currently there is limited availability of these tapes in EDs in the Western Cape. This may be due to lack of awareness amongst Unit Managers as to its efficacy. Cost may have been an issue previously but the tapes are now freely available in this country for around R300. The complete Broselow system of pre-packaged, colour coded resuscitation packs are more expensive and may be impractical financially for most state run units.

There is a need to make the Broselow tape more locally acceptable. This would include changing the names of drugs to those used locally eg. epinephrine to adrenaline, and lidocaine to lignocaine. We would also need to ensure that drugs are packaged in the same concentrations and doses here compared to those listed on the tape.

In our limited resource environment it may be necessary to adapt the length-based system to our needs. Practical ways of doing this include:

- Placing length markings on the sides of trauma stretchers to measure children
- Creating local length-based tables and displaying these prominently in EDs

- Creating tape measures with premarked divisions indicating different categories for simple weight categorization: these can be teamed with appropriate sets of equipment
- Have EDs make up their own packages of weight-based resuscitation equipment to match length tables or tapes

6.6.1 SOUTH AFRICAN POPULATION WEIGHTS

In researching this study a lack of local data on child health and child growth was noted. The only available South African growth indices are from the WHO in 2000 and the Health of the Nation study in 2000. These indices may already have changed. In fact in South Africa we have no local growth charts, but are using the CDC charts which are USA population derived. This is obviously not ideal.

In order to make assumptions about critically ill children it is important that we be aware of normal trends in our population, not only with regards to weight but also in terms of vital signs. Local growth charts may allow us to develop a locally applicable age or length based method of weight estimation.

The burden of disease in South Africa is high. We are constantly faced with large numbers of very sick children. In 2003 it was estimated that our under 5 year mortality rate was an alarming 66/1000 live births (Burden of Disease Project 2007): unfortunately, this trend appears to be increasing rather than decreasing in the last 5 years. The commonest causes of death in the 1-4 year age group were HIV/Aids, Road traffic accidents, Intentional injury and Diarrhoea (Burden of Disease project 2007).

In the Western Cape we are more fortunate. The provincial under 5 year mortality rate is 46/1000 live births. But there are very large geographical differences with lower socio-economic areas having rates comparable with the rest of the country. These patterns of inequity are also reflected in our nutritional statistics. In the Western Cape 16.5% of children are stunted [height-for-age <2 SD of international reference] and 5% are wasted [weight-for-height < 2 SD of international reference] (Burden of Disease Project 2007).

6.7 ERROR REDUCING STRATEGIES

The potential medication error rate in EDs is estimated at around 10% (Kozer 2002). This is a worrying statistic in that it does not include other potential errors in diagnosis, procedures and therapy. Dosing errors are the most common type of medication error. In paediatric practice where drug dosages have to be calculated by weight, dosing errors occur frequently (Kaushal 2001).

South African healthcare workers battle daily with large patient loads, unpleasant working conditions, limited resources and long working hours. In the ED there is also the constant pressure to rapidly move patients through the system. This is compounded by the fact that many young doctors with little training or experience in paediatrics are often left unsupervised. These doctors are often only rotating through the department and have not yet had time to become comfortable with the staff and processes.

Patient factors may increase the potential for error. We have large numbers of very sick patients. There is often not enough time or it may be impossible to get a history of allergy or contraindications, before any medication has to be given. Language barriers in our community may aggravate this.

For those new to paediatric care, the drugs may be unfamiliar. In departments where children are not often seen staff may not be aware of the need to dilute certain drugs before administration. The calculation of the drug dose is most often the root of the problem.

There is a need for awareness of the potential for error in South African EDs. This potential is increased in the management of paediatric patients. At management level strategies should be put in place to minimise this risk and ensure patient safety.

- A dedicated paediatric resuscitation area should be created in every ED. This is to be stocked with appropriate paediatric sized equipment and tools to aid weight estimation.
- Scales and measuring tapes should be available in every ED

  In situations where it not feasible to weigh the child, Weight Tables or tapes should be available
- Weight estimation methods that have been validated for the local population should be used.
- Practice guidelines and protocols should be developed to allow for a safe standard of care for even the most inexperienced clinician.
- A healthcare worker should be assigned the task of note-taker during resuscitations to independently check drug and equipment dosages and document these.

- Pharmacy should supply prepackaged paediatric-sized or focused medications eg. adrenaline diluted to 1:10 000 or 10 % Dextrose
- A clinical pharmacist should form part of the team or be available for questions.
- It would be useful to add age-range markings on equipment as guides to acceptable therapy eg. Defibrillators, ventilators.
- A system of resuscitation training for junior doctors to decrease the anxiety associated with resuscitations, increased supervision and clinical support may also reduce error.
- A system that allows for error reporting for the purposes quality management without prejudice or fear of persecution should be developed eg. Adverse event forms, telephonic reporting systems
- Feedback on errors should be provided with appropriate remedial training or streamlining of hospital processes.

The evidence is not strong enough yet to decide whether APLS or Broselow ® Tape is the most accurate weight estimation method in South Africa, but this may not be the important question. What we should rather be looking at is which method provides us with the most appropriate clinical interventions. Our ultimate goal is a successful resuscitation.

The APLS formula has proven to be accurate in our population. It is familiar to most practitioners in this country. It is easy to remember and allows for simple mental arithmetic. It does not require any resources and so can be used in any environment. Where prehospital notification occurs, it can be used to calculate estimates of drug doses and equipment before the patient arrives in the ED. Even though it underestimates weight statistically, the differences clinically may not be pronounced, particularly in smaller children. The onus is on the clinician to judge whether the estimate is accurate and also to continuously reassess the patient's response to any intervention. In higher socioeconomic groups it is probable that the APLS formula will underestimate weight more significantly.

Ideally Broselow tapes should be available in all EDs. It provides a reasonably accurate assessment of weight. It reduces cognitive load and reduces the potential for medication error. Training in the correct use of the tape should be provided to all staff. Where resources allow use of the full Broselow system, this should be implemented. Elsewhere length appropriate equipment should be packaged or stored together for ease of use.

The "Gold Standard" will always be a measured weight. As soon as the patient is stable every effort should be made to weigh the child. This allows for accurate management during the course of their hospital stay. Trolley or bed scales should be standard equipment in units where seriously ill or injured children are treated.

There is a need for a prospective multicentre study to validate the Broselow tape for the South African population across all socioeconomic and ethnic groups. It may be necessary to repeat this kind of research every 10 to 20 years as the growth patterns in the country change

CHAPTER 7: CONCLUSION

This study has shown that both APLS formula and the Broselow tape are valid weight estimation methods in the South African population. The Best Guess and Luscombe & Owen methods for weight estimation are inaccurate and should not be used for Western Cape children. Use of these methods leads to a significant error rate in both drug dosing and equipment size.

While this research may be considered valid for children in the Western Cape, caution must be applied when extrapolating the results to the rest of the country, as areas of higher poverty and higher rates of malnutrition and growth stunting may produce different results. This research should be repeated in other areas of South Africa: areas with high levels of poverty are inevitably associated with poorer health service delivery, and the benefits of an accurate, simple to remember resuscitation aide will be even bigger in such areas. Conversely, wealthy populations are more likely to be Westernised and suffer from higher rates of obesity and overweight and therefore be underestimated by these formulae: caution should therefore also be applied in such areas.

However, even with such cautions, the APLS or Broselow methods may be applied in the resuscitation of paediatric population in the South African setting, until further research is undertaken.

CHAPTER 8: RECOMMENDATIONS

This study has shown that both APLS and the Broselow tape are valid weight estimation methods in the South African population. Therefore the following recommendations are made:

- At South African health facilities (including ambulance services) where paediatric resuscitations occur, healthcare personnel should be trained in the use of the APLS formula and / or have the Broselow tape readily available and be trained in its use.
- This research should be repeated on populations throughout the country, taking note to compare results across social groups, including wealthy, middle class, lower class and informal housing sectors.
- Strategies should be developed to minimise errors in Emergency Medicine particularly in high risk practice such as paediatric emergency care. The Broselow® Tape would be useful in this regard.

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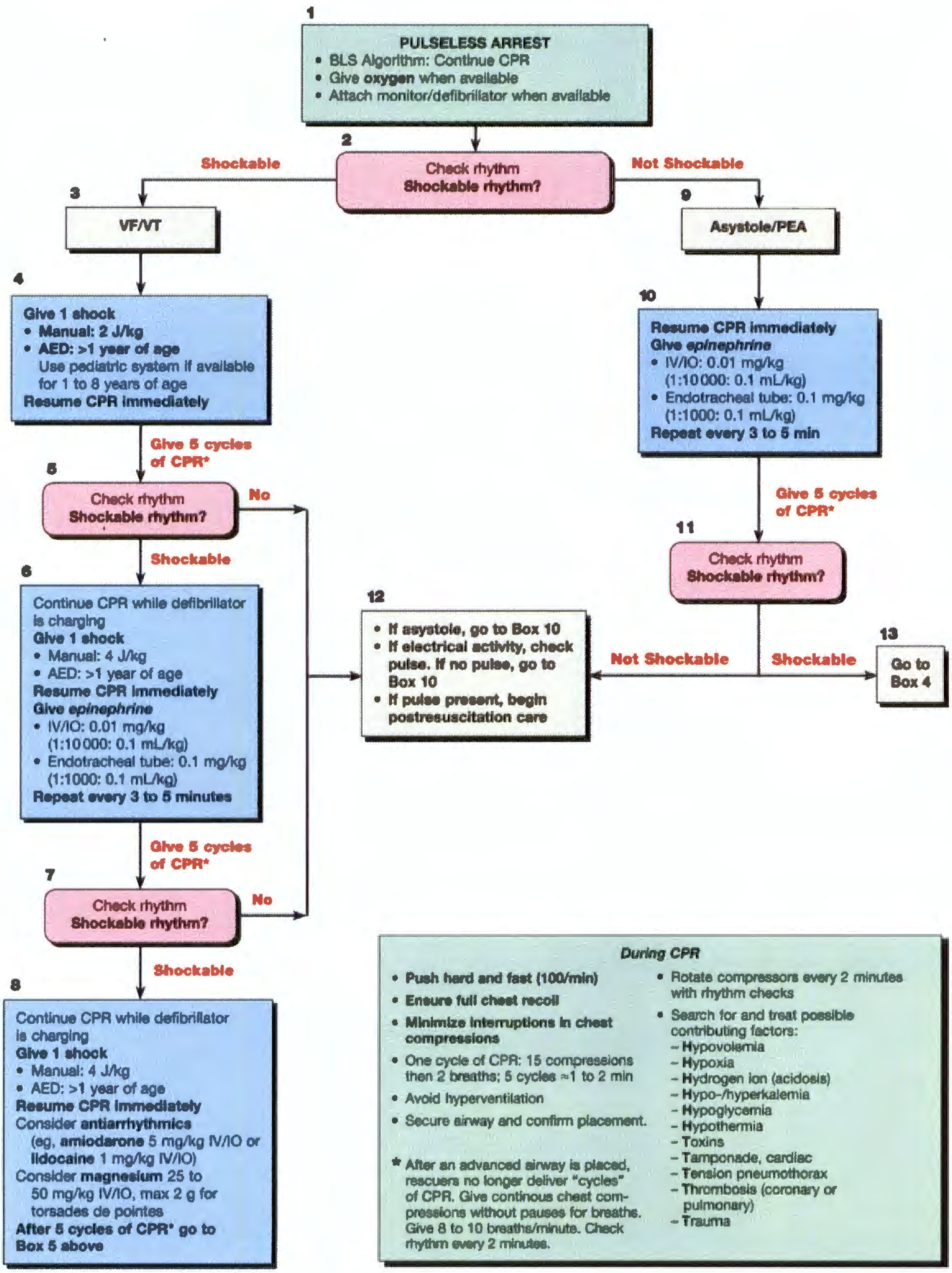
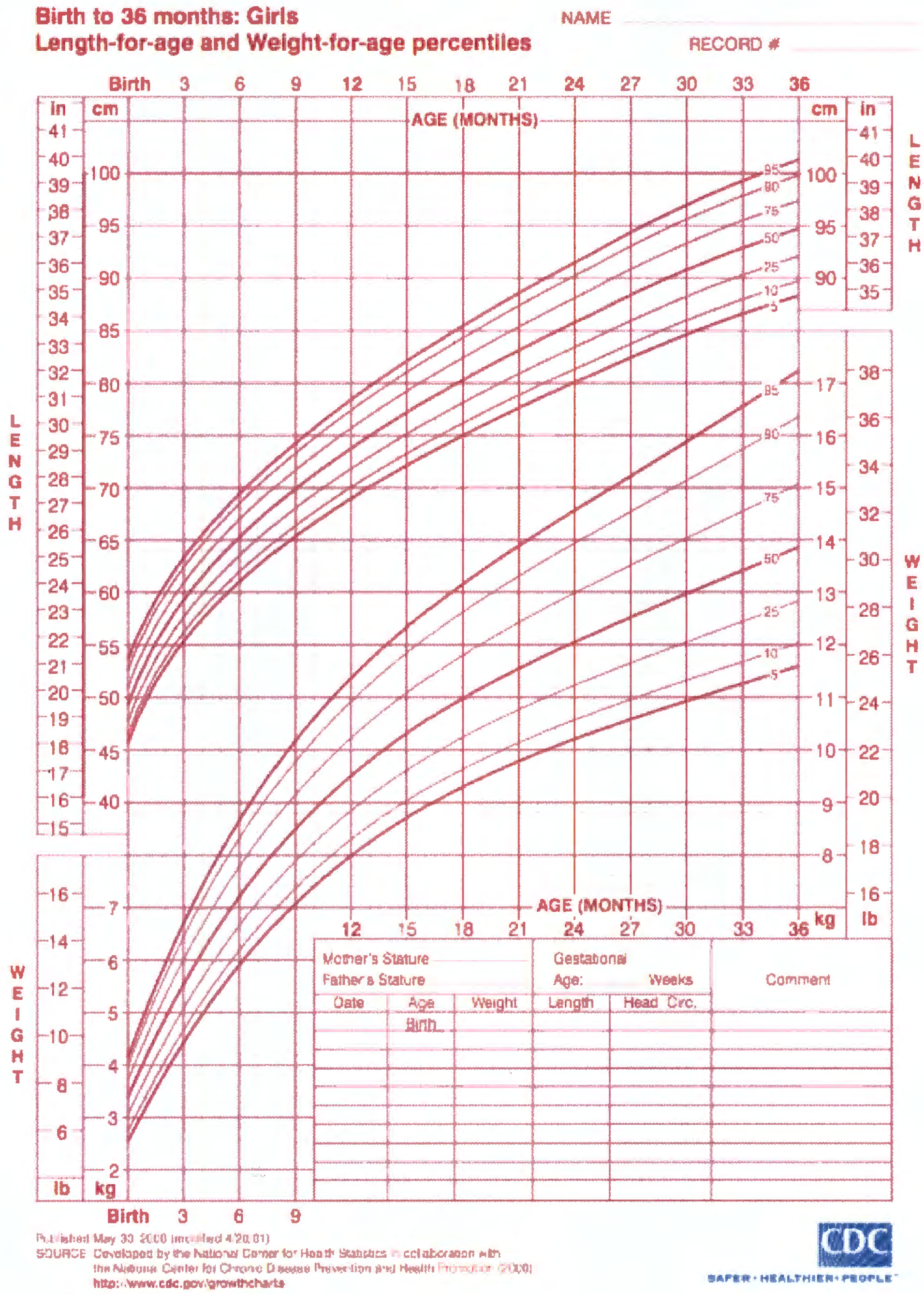
APPENDICES

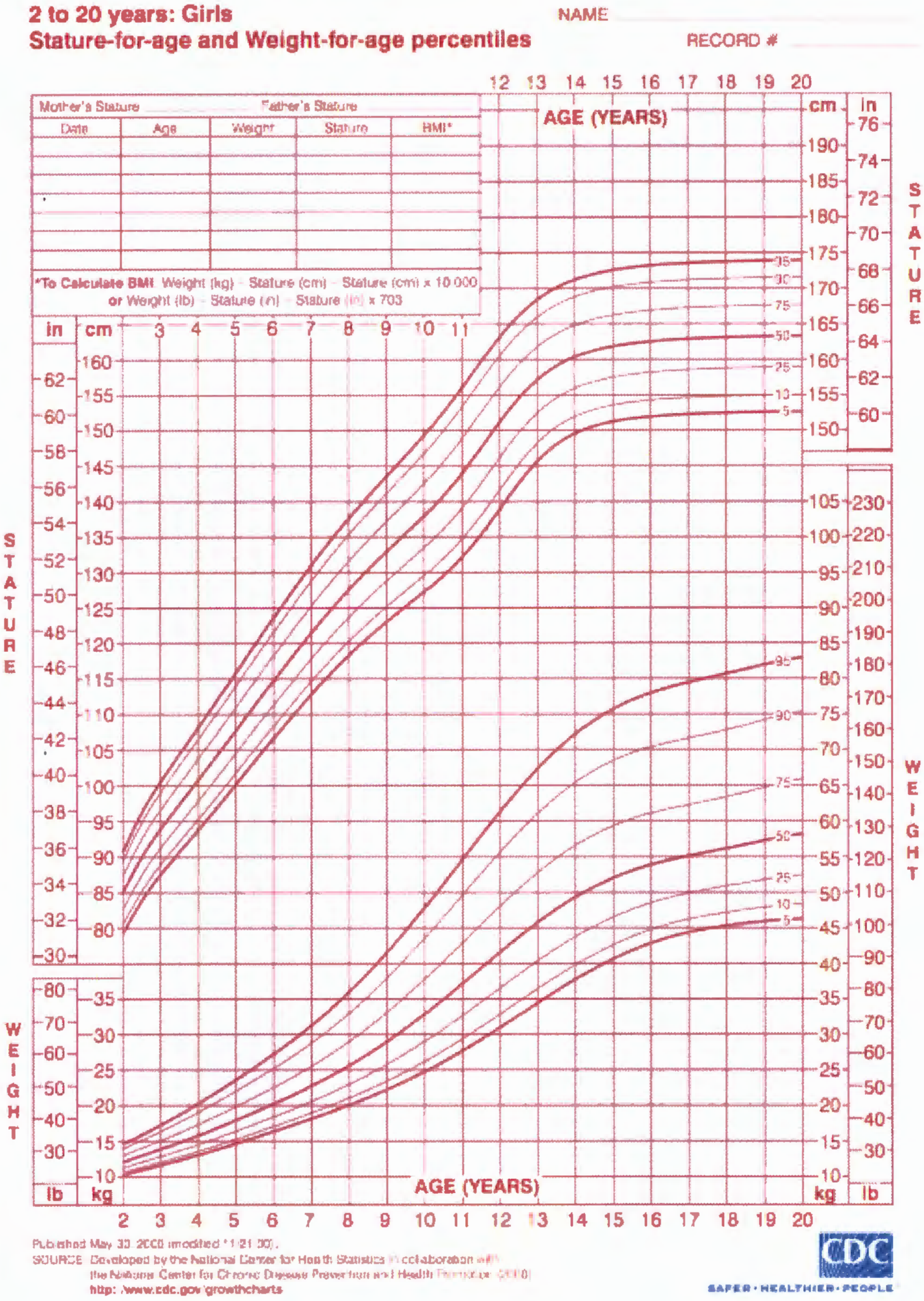
A. ILCOR/AHA/ERC Paediatric Life Support Algorithm (ILCOR 2005)



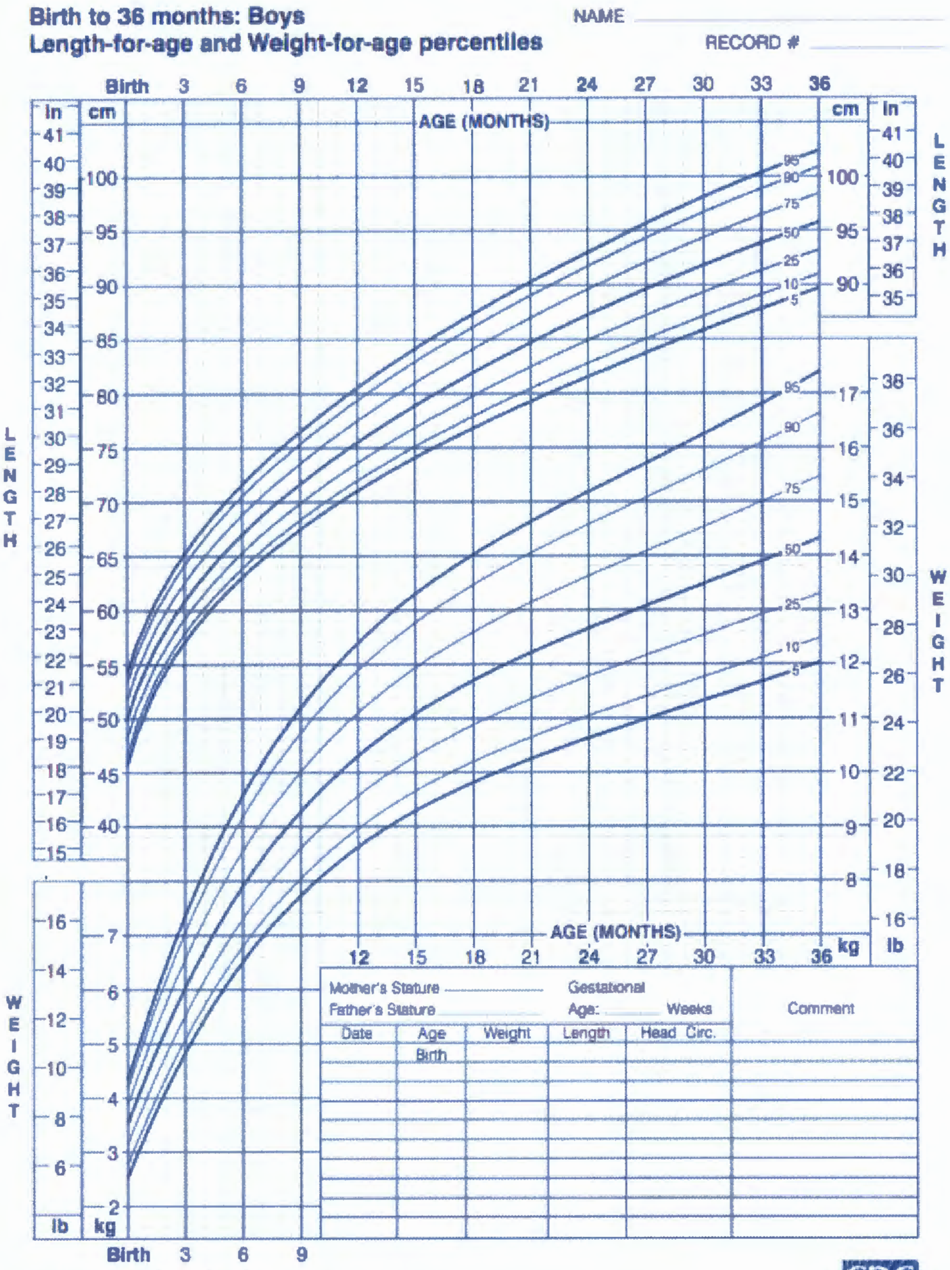
B. CDC growth Charts (2000) Female 0-2 years



CDC Growth Charts **Female 2-20 years**



CDC Growth Charts **Male 0-2 yrs**



Published May 30, 2000 (modified 4/20/01)
SOURCE: Developed by the National Center for Health Statistics in collaboration with the National Center for Chronic Disease Prevention and Health Promotion (2000).
http://www.cdc.gov/growthcharts

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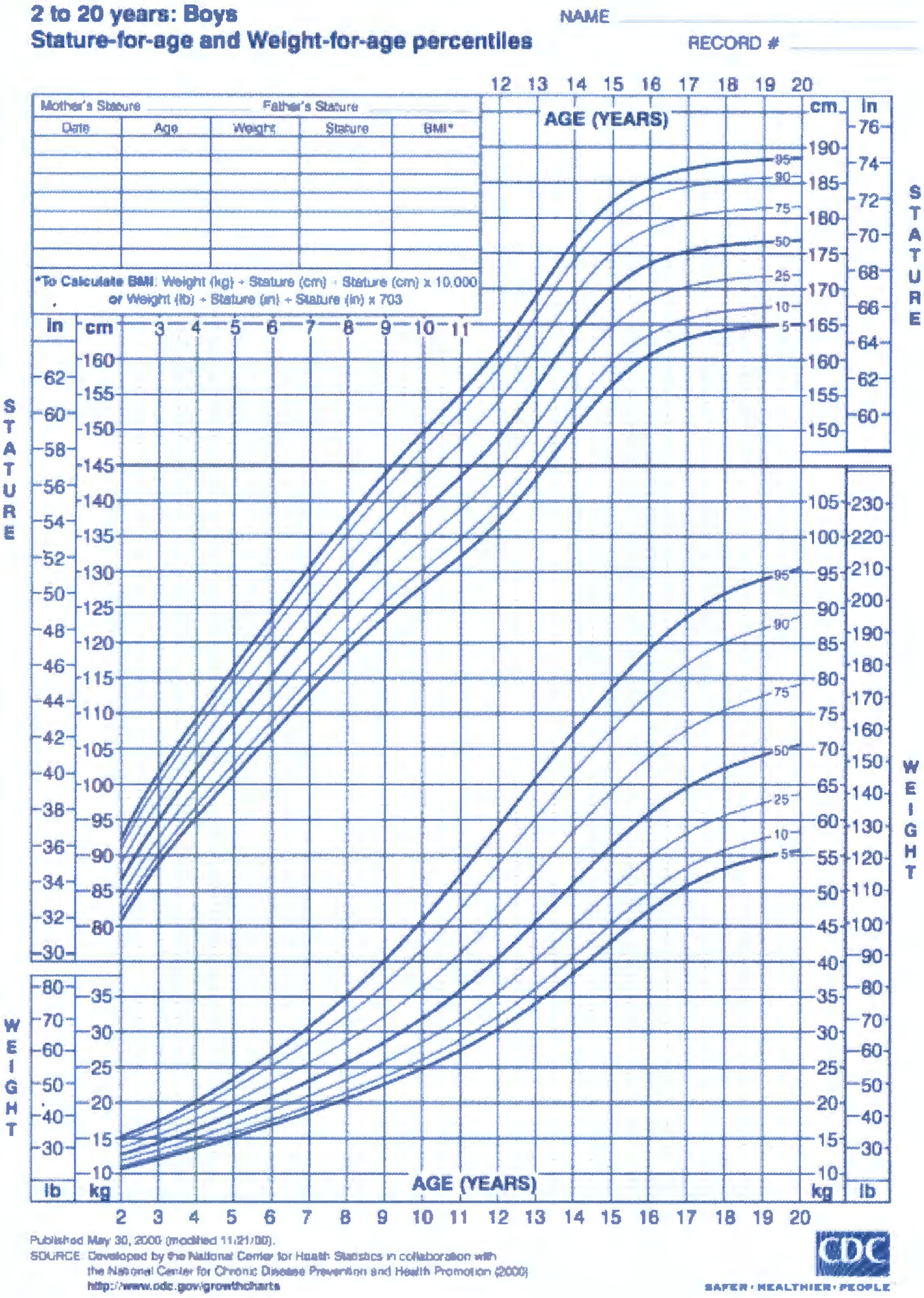
CDC Growth Charts

Male 2-20 years



Published May 30, 2000 (modified 11/21/00).
SOURCE: Developed by the National Center for Health Statistics in collaboration with the National Center for Chronic Disease Prevention and Health Promotion (2000).
http://www.cdc.gov/growthcharts

C. IMCI System Weight for Age charts (WHO 2005)

APPENDIX 5

Assessing nutritional status

A5.1 Calculating the child's weight-for-age

To calculate a child's weight for age, use the table below or the chart on page 363. For using the table:

- Locate the row containing the child's age in the central column of Table 34.
- Look to the left in that row for boys, and to the right for girls.
- Note where the child's weight lies with respect to the weights recorded in this row.
- Look up the adjacent column to read the weight-for-age of the child.

  Example 1: Boy: age 5 months, weight 5.3 kg: He is between -2 and -3 SD

  Example 2: Girl: age 27 months, weight 6.5 kg: She is less than -4 SD

The lines in the chart on page 363 correspond to -2 (low weight-for-age) and -3 SD (very low weight-for-age).

Please note that you should use Table 35 on page 365 for weight-for-height to determine whether a child is severely malnourished.

WEIGHT/HEIGHT

Table 34. Weight-for-age

Boys' weight (kg)					Age	Girls' weight (kg)				
-4SD	-3SD	-2SD	-1SD	Median	(months)	Median	-1SD	-2SD	-3SD	-4SD
1.53	2.04	2.45	2.86	3.27	**0**	3.23	2.74	2.24	1.75	1.26
1.55	2.24	2.92	3.61	4.29	**1**	3.98	3.39	2.79	2.19	1.59
1.70	2.62	3.47	4.33	5.19	**2**	4.71	4.03	3.35	2.67	1.99
2.18	3.13	4.08	5.03	5.98	**3**	5.40	4.65	3.91	3.16	2.42
2.73	3.72	4.70	5.69	6.68	**4**	6.05	5.25	4.46	3.66	2.67
3.34	4.33	5.32	6.31	7.30	**5**	6.65	5.82	4.98	4.15	3.31
3.94	4.92	5.89	6.87	7.85	**6**	7.21	6.34	5.47	4.60	3.73
4.47	5.44	6.41	7.37	8.34	**7**	7.71	6.80	5.90	5.00	4.09
4.92	5.89	6.85	7.82	8.78	**8**	8.16	7.22	6.29	5.35	4.42
5.30	6.27	7.24	8.21	9.18	**9**	8.56	7.59	6.63	5.66	4.70
5.62	6.60	7.58	8.56	9.54	**10**	8.92	7.92	6.93	5.93	4.94
5.88	6.88	7.87	8.87	9.86	**11**	9.24	8.22	7.20	6.17	5.15

IMCI Chart – Equipment by Age group

APPENDIX 3

Equipment size for children

Appropriate sizes of paediatric equipment according to age (weight) of child

Equipment	0–5 months (3–5 kg)	6–12 months (4–9 kg)	1–3 years (10–15 kg)	4–7 years (16–20 kg)
Airway and breathing				
Laryngoscope	straight blade	straight blade	child macintosh	child macintosh
Uncuffed tracheal tube	2.5–3.5	3.5–4.0	4.0–5.0	5.0–6.0
Stylet	small	small	small/ medium	medium
Suction catheter (FG)	6	8	10/12	14
Circulation				
IV cannula	24/22	22	22/18	20/16
Central venous cannula	20	20	18	18
Other equipment				
Nasogastric tube†	8	10	10–12	12
Urinary catheter†	5 feeding tube	5 feeding tube/F8	Foley 8	Foley 10

† Sizes in French gauge (FG) or Charrière, which are equivalent and indicate the circumference of the tube in millimetres.

D. Broselow Tape and Broselow System

Simplified Broselow®-Luten System (DEPS 2002)

Colour coded packages of equipment corresponding with colour coded weight ranges on BLT.