STATURE, SEX AND WEIGHT ESTIMATION FROM FOOTPRINT AND FOOT OUTLINE DIMENSIONS OF SELECTED ETHNIC GROUPS IN SARAWAK FOR FORENSIC INVESTIGATION

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by

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LIST OF ABBREVIATIONS

2D	2-Dimensional
3D	3-Dimensional
AUC	Area Under the Curve
AutoCAD 2010	Auto Computer Aided Design 2010
BFS	Bidayuh Female Stature
BFW	Bidayuh Female Weight
BL	Base Line
BMS	Bidayuh Male Stature
BMW	Bidayuh Male Weight
BOB	Ball Outline Breadth
BPB	Ball Print Breadth
BPSS	Bidayuh Pooled Sample Stature
BPSW	Bidayuh Pooled Sample Weight
cm	Centimeter
CMM	Calcaneal Concavity Medial
CTL	Calcaneal Tubercle Lateral
DLA	Designated Longitudinal Axis
DNA	Deoxyribonucleic acid
F	Frequency
FB1	Federal Bureau of Investigation
F.T	Fourth Toe
G.T	Great Toe
H	Heel

HOB	Heel Outline Breadth
HPB	Heel Print Breadth
IFS	Iban Female Stature
IFW	Iban Female Weight
IMS	Iban Male Stature
IMW	Iban Male Weight
IPSS	Iban Pooled Sample Stature
IPSW	Iban Pooled Sample Weight
kg	Kilograms
L	Left
L.B	Lateral Ball
L.T	Little Toe
LBFS	Lun Bawang Female Stature
LBFW	Lun Bawang Female Weight
LBMS	Lun Bawang Male Stature
LBMW	Lun Bawang Male Weight
LBPSS	Lun Bawang Pooled Sample Stature
LBPSW	Lun Bawang Pooled Sample Weight
LMP	Lateral Metatarsal Point
LOBB	Left Outline Ball Breadth
LOHB	Left Outline Heel Breadth
LPBB	Left Print Ball Breadth
LPHB	Left Print Heel Breadth
m	Meter
M.B	Medial Ball

MD	Mean Difference
MFS	Melanau Female Stature
MFW	Melanau Female Weight
mm^2	Milimeter square
MMP	Medial Metatarsal Point
MMS	Melanau Male Stature
MMW	Melanau Male Weight
MPSS	Melanau Pooled Sample Stature
MPSW	Melanau Pooled Sample Weight
n	Sample size
OP	Mid-rear Heel Outline Point
P	Mid-rear Heel Print Point
R	Right
R	Correlation Coefficient
R^2	Coefficient of Determination
RD	Ridge density
ROBB	Right Outline Ball Breadth
ROC	Receiver Operating Characteristic
ROHB	Right Outline Heel Breadth
RPBB	Right Print Ball Breadth
RPHB	Right Print Heel Breadth
SEE	Standard Error of Estimate
S.T	Second Toe
SD	Standard Deviation
SNP	Single-Nucleotide Polymorphism

SPSS	Statistical Package for Social Sciences
T.T	Third Toe
T-1	Great Toe
T-2	Second Toe
T-3	Third Toe
T-4	Fourth Toe
T-5	Little Toe
TFPRD	Total Footprint Ridge Density
USM	Universiti Sains Malaysia
VNTR	Variable Number Tandem Repeat
W	Weight

LIST OF SYMBOLS

=	Equal
<	Less than
%	Percentage

ANGGARAN KETINGGIAN, JANTINA DAN BERAT DARIPADA UKURAN JEJAK TAPAK KAKI DAN JEJAK GARIS LUAR TAPAK KAKI KUMPULAN ETNIK YANG TERPILIH DI SARAWAK UNTUK PENYIASATAN FORENSIK

ABSTRAK

Jejak tapak kaki dan jejak garis luar kaki adalah bukti fizikal dan bukti surihan yang lazimnya ditinggalkan di tempat kejadian jenayah yang boleh digunakan untuk menubuhkan anggaran ketinggian, jantina dan berat badan. Tujuan kajian ini adalah untuk menganggarkan spesifik populasi dan spesifik jantina daripada jejak tapak kaki dan jejak garis luar tapak kaki untuk ketinggian dan berat badan serta anggaran jantina daripada penghitungan ketumpatan rabung kumpulan etnik terpilih yang tinggal di negeri Sarawak, Malaysia Timur iaitu Iban, Bidayuh, Melanau dan Lun Bawang. Ketinggian, berat badan, jejak tapak kaki dan jejak garis luar tapak kaki direkodkan mengikut prosedur piawai. Data yang diukur untuk ketinggian dan anggaran berat badan dan juga jejak kaki yang dikira daripada lapan saiz yang ditetapkan $25mm^2$ dianalisis dengan perisian statistik SPSS 20 untuk formula linear dan juga anggaran potensi seksual dengan Keluk Karakteristik Pengendali Penerima (ROC). Kesemua panjang jejak tapak kaki dan jejak garis luar tapak kaki menunjukkan korelasi positif ketara (P<0.001) dengan ketinggian. Salah satu penemuan telah menunjukkan pekali korelasi yang sangat tinggi antara panjang jejak tapak kaki sampel dikumpulkan (*R*: 0.861-0.887) dengan ketinggian. Sebaliknya, korelasi positif yang signifikan (P<0.001) hanya dapat dilihat di antara lebar bola medial di kedua-dua dimensi jejak tapak kaki dan jejak garis luar tapak kaki dengan berat badan. Dalam jejak tapak kaki, pekali korelasi yang lebih tinggi diperoleh antara dimensi bola medial sample terkumpul dengan berat badan (*R*: 0.262-0.356). Dalam perkiraan jantina, ketumpatan rabung tapak kaki adalah jauh lebih tinggi di kalangan perempuan

berbanding lelaki di semua kawasan yang ditentukan (*P*<0.05). Satu daripada penemuan menunjukkan kepadatan ridge tapak adalah masing-masing 91.6% dari kanan dan 99.9% dari kaki kiri. Kesimpulannya, jejak tapak kaki dan dan jejak garis luar tapak kaki dapat membantu menentukan identiti jenayah dalam siasatan forensik.

STATURE, SEX AND WEIGHT ESTIMATION FROM FOOTPRINT AND FOOT OUTLINE DIMENSIONS OF SELECTED ETHNIC GROUPS IN SARAWAK FOR FORENSIC INVESTIGATION

ABSTRACT

Footprints and foot outlines are physical and trace evidences commonly left at crime scene that can be used to establish stature, sex and body weight estimation. The aims of this study were to estimate population specific and sex-specific from footprints and foot outlines for stature and body weight as well as sex estimation from ridge density counting of selected ethnic groups residing in Sarawak state, East Malaysia i.e Iban, Bidayuh, Melanau and Lun Bawang. The stature, body weight, footprints and foot outlines were recorded following the standard procedure. The measured data for both stature and body weight estimation and also the counted footprint ridges from the eight defined size of $25mm^2$ were analysed with SPSS 20 statistical software for linear regression formulae derivation and also sexing potentials estimation by Receiver Operating Characteristic (ROC) curve. All of the footprint and foot outline lengths show significant (P<0.001) positive correlation with stature. One of the findings had shown extremely high correlation coefficient between footprint lengths of pooled samples (R: 0.861-0.887) with stature. In contrast, the positive significant (P<0.001) was only evident between breadth at ball of both footprint and foot outline dimensions with body weight. In footprints, the higher correlation coefficient was obtained between breadth at ball dimensions of pooled sample and body weight (R: 0.262 – 0.356). In sex estimation, the mean of footprint ridge density was significantly higher among females than males in all designated areas (P<0.05). One of the findings demonstrated total footprint ridge density was 91.6% from the right and 99.9% from the left foot respectively. In conclusion, footprints and foot outlines can help to determine criminal’s identity in forensic investigation.

CHAPTER 1

INTRODUCTION

1.1 Forensic Anthropology

Anthropology is defined as the science of human beings exclusively about the study of human beings and their ancestors through time and space and in relation to physical character, environmental and social relations and culture. Confederation between forensic and anthropology yield “Forensic Anthropology” that refer to the application of the anatomical science and its various sub-fields include forensic archaeology and forensic anatomy (Nawrocki, 2006).

Anthropologists use human skeletal differences as the basis of human identity determination. The idea on skeletal differences promotes to the developments anthropometry, the study of human body measurements especially on a comparative basis. This study leads to an invention of Bertillon Method, the method of skeletal measurements by Alphonse Bertillon (Rhodes and Henry, 1956). The potential value of anthropologist in assisting identification of skeletal remains was publicly advertised in Federal Bureau of Investigation (FBI) Law Enforcement Bulletin by Krogman in 1940s. The forensic anthropology then officially began in 1950s when the U.S. Army Quartermaster Corps employed forensic anthropologist in the identification of war victims in Korean War (Snow and Clyde, 1982). An entry of large number of skeletons for study facilitates the derivation of more accurate formula for the identification of sex, age (Mc Kern, 1957) and stature using skeletal characteristic (Trotter, 1952).

Nowadays, forensic anthropology is well established discipline in forensic science and has raised public attention as forensic anthropologist started working on high profile cases. In line with forensic pathologist, forensic dentists and homicide investigators, forensic anthropologist commonly testifies in court as expert witnesses. The anthropometry measurements were vastly applied and utilised by forensic anthropologist and forensic podiatrist for identification purposes.

1.1.1 Forensic Podiatry-Application of anthropometry measurements

Forensic podiatry subdiscipline is an application of podiatric medical expertise to legal system, and further defined by Vernon (1990) as "application of sound and researched podiatric knowledge in the context of forensic and mass disaster investigations. This may be for the purpose of person identification, to show the association of an individual with the scene of crime, or to answer any other legal question concerning the foot or footwear that requires knowledge of the functioning foot."

Forensic anthropologist and others have used human foot and its impression to forensically determine height (Kanchan *et al*., 2012, 2010; Krishan, 2008a; Jasuja *et al*., 1991;1993;1997), weight (Aurichio, 2011; Irene and Nashwa, 2010; Oladipo *et al*., 2009; Atamturk and Duyar, 2008; Grivas *et al*., 2008; Krishan, 2008b; Bavdekar *et al*., 2006), gender (Sen *et al*., 2011, Atamturk, 2010; Zeybek *et al*., 2008; Ozden *et al*., 2005) or other measurements of a person. Footprint is a physical evidence as fingerprints, that speaks to itself and requires no explanation, only identification. Fingerprints evidence are likely found at the crime scene, however not always because the offenders may take precautionary measures i.e. wearing gloves to conceal evidence and preclude identification. But it is impossible for the individual to enter and leave the crime scene without using his/her feet (Dimaggio, 2005).

Forensic podiatrist is responsible for the establishment of personal identity in forensic investigations especially in the case of dismembered remains of mass disasters, terrorist attacks, mass murders, transport accidents, tsunamis, floods and earthquakes. According to Bodziak (1990), foot impression evidence is normally found on ground surfaces, such as dirt, tile, concrete and carpeting but seldomly found on counter-tops or other less common locations. Any prints that are momentary in nature such as in snow must be immediately dealt with and processed.

In tragic mass disaster such as high-power explosions and bomb blasts, air plane crashes and other high impact transportation accident, the potential recovery of feet (often enclosed in shoes), separate from body are relatively high, hence the demand in forensic identification from foot become intensified (Krishan, 2008c).

Moreover, in the past it has been successfully reported that there is significance value of human foot and its bones and also footprints in forensic identification. The remarkable importance of foot in identification has been confirmed and published in the literature on estimation of sex from foot bones and foot dimensions (Case and Ross, 2007; Krishan *et al.*, 2010; Abel *et al.*, 2008; Sen *et al.*, 2011), individualistic and unique features of the foot and footprints (Robbins, 1978, 1985; Reel *et al.*, 2010; Laskowski and Kyle, 1988; Kennedy *et al.*, 2003; Krishan, 2007), and the use of radiographic comparisons of the foot (Owsley and Mann, 1989; Rich *et al.*, 2002, 2003; Sudimack, 2002; Dean *et al.*, 2005). Other studies on stature estimation from human foot bones (Bidmos, 2006, 2008; Byers, 1989; Holland,1995; Bidmos and

Asala, 2006), foot dimensions (Ozden *et al*., 2005; Sanli *et al*., 2005; Krishan, 2007; Sen and Ghosh, 2008; Zeybek *et al*., 2008; Kanchan *et al*., 2008; Jasuja and Singh, 1991; Saxena, 1984; Qamra and Deodhar, 1986; Gorden *et al*., 1989), footprints and foot outline (Barker and Scheuer,1998; Krishan, 2008a; Robbins,1986) has also affirmed that the stature can successfully be estimated from human foot, its bones and its impression for forensic and legal examinations.

1.1.2 Biological profiling from footprint and foot impression

Forensic anthropologists are key player in medico legal community (Byers, 2011), responsible to discover, record and collect footprint for further examination. The comparative analysis in foot between an unknown specimen with a known specimen may lead to positive identification. The foot is unique, complicated in structure, genetically manufactured that need years of experience to distinguish all the complexities including soft tissue and skeletal pathologies for forensic evaluation. The personal identity can be established from foot because none of two individuals including identical twin are alike in foot anatomical, morphological and biomechanical configuration (Dimaggio, 2005).

Due to medico legal interest, forensic anthropologist develops biological profiles from human foot and its impression to determine height (Kanchan *et al*., 2012: 2010; Krishan, 2008a; Jasuja *et al*., 1991; Jasuja and Manjula 1993; Jasuja *et al*., 1997), weight (Aurichio *et al*., 2011; Irene and Nashwa, 2010; Oladipo *et al*., 2009; Atamturk and Duyar, 2008; Grivas *et al*., 2008; Krishan, 2008b; Bavdekar *et al*., 2006) or gender (barefoot analysis) (Rao and Kotian, 1990).

Limited prediction of biological profile from foot dimensions create challenges in forensic investigation to provide authenticate evidence with regards to subjects, scene and action potentially connected to crime. In order to minimise doubt in evidence evaluation and attachment of specific legal implications, high accuracy and precise measurement approaches are needed in predicting biological profile for stature, body weight and sex from footprints (Zoltan, 2005; Cunha, 2009; Azis, 2016).

1.1.3 Stature estimation and body weight estimation

Stature and body weight are two of the biological attributes to establish individual identity. These attributes can be estimated from footprints (Irene and Nashwa, 2010; Krishan, 2008a; Krishan, 2008b) and foot outlines. Previous studies have demonstrated highly significant positive correlation between both stature and body weight from footprints and foot outlines dimensions. Footprint and foot outlines are defined as follows.

1.1.3 (a) Footprints

The two-dimensional (2D), which also known as footprint is found when the foot's plantar surface touches the floor or hard surface such as newly waxed floor, freshly cemented surfaces, moistened surfaces in dust, oil and paint.

1.1.3 (b) Foot outlines

The three-dimensional (3D) is formed as the foot plantar surfaces entered into soft soil, or mud.

1.1.4 Sex estimation from footprint ridge density

Sex is also a biological attribute to estimate gender of individuals. Sex can be estimated from footprint ridge density because the distance between ridges and also the thickness of the ridges is subjected to overall sexual dimorphism. Males have larger feet, hence results in greater distances and thicker ridges than females (Kanchan *et al.*, 2012; Krishan *et al*., 2014). Sexing potential from footprint and toe print is possible since in a defined area, males have fewer number of ridges than females (Cummins *et al*.,1941; Ohler *et al*., 1942).

1.2 Objectives of the study

The general and specific objectives of this study were as follows:

1.2.1 General objective

To estimate stature, body weight and sex among selected ethnic groups in Sarawak i.e. Iban, Bidayuh, Melanau and Lun Bawang.

1.2.2 Specific Objectives

1. To derive simple linear regression equations and multiple linear regression equations from footprint length and foot outline length for estimation of stature from Iban, Bidayuh, Melanau and Lun Bawang ethnics.

2. To derive simple linear regression equations and multiple linear regression equations from various footprint and foot outline dimensions for estimation of body weight from Iban, Bidayuh, Melanau and Lun Bawang ethnics.

3. To estimate sexing potential from toeprint and footprint ridge density counting among Iban, bidayuh, Melanau and Lun Bawang ethnics.

1.3 Research Hypothesis

The Null hypothesis of this study are:

1. The independent variables have no significant (P < 0.001) predictive capability toward the estimation of stature.
2. The independent variables have no significant (P < 0.001) predictive capability toward the estimation of body weight.
3. The mean footprint ridge density is not significantly higher among females than males in all designated areas (P < 0.05).

1.4 Problem Statements

There is no study on stature, body weight and sex estimation among Iban, Bidayuh, Melanau and Lun Bawang ethnics that has been reported in Sarawak. The development of biological profile for stature, body weight and sex estimation are based on specific populations. Thus, the accuracy of the estimation is achieved when the formula applied to the same population from which they are derived (komar, 2003; Iscan, 2005).

Human morphological features rely geographical distribution, regions of country and racial characteristics (Jaydip and Ghosh, 2008). Hence the derivation of population specific formula for Iban, Bidayuh, Melanau and Lun Bawang are essential.

1.5 Potential Benefits

The sex-specific and population-specific (Iban, Bidayuh, Melanau and Lun Bawang) linear regression and multiple linear regression equations derived serve as concrete evidence to identify person or suspect possibly involved in crime. The sex estimation from ridge densities are established to narrow down the investigation for sex identification. The two biological profiles (stature and body weight) are statistically developed with standard error of estimates (SEE). Those established profiles serve as reliable evidence in criminal prosecution because the derived formulae are calculated with estimated error.

1.6 Thesis Outline

The outline of this study is as follows: The first chapter gives overview forensic anthropology, forensic podiatry-application of anthropometry measurements, biological profiling from footprint and foot impression, stature estimation and body weight estimation, sex estimation from footprint ridge density, objectives of the study, research hypothesis, problem statements and potential benefits.

The second chapter is the reviews on human variations, genetic influences, environmental influences on human variations (physical environment, warm and hot climate and cold climate), nutrition and disease, altitude, socio-economic status, urbanisation, and smoking and other toxins, secular trends in growth with reference to stature, secular trends in growth with reference to body weight, footprint measurement techniques (Gunn Method, Optical Center Method, Reel Method, Overlay/Dimaggio Modified Overlay Method, Ridge density counting), literature review on stature estimation from footprint length and foot outline length measurements, literature review on body weight estimation from various footprint measurements, literature review on sex estimation from footprint ridge density and review on cases related to footprints.

The third chapter is on the methodologies employed for stature, body weight and sex estimation which includes sample size, data collection and statistical analysis.

The fourth chapter emphasises on the research findings. This chapter elucidates individual ethnic based regression equations ideally for stature and body weight estimation and also the results of the ROC analysis to find the predictability of each variable in sex estimation.

The fifth chapter provides discussion for the overall findings.

The sixth chapter includes the conclusion, limitation of the study and the recommendation for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Human belongs to the same polytypic species, *Homo Sapiens.* A polytypic species means local population differ in the expression of one or more trait. Hence, phenotypic and genotypic variations is linked with individuals within a local population. Traditionally, population are classified according to various characteristics such as skin colour, hair colour, hair form i.e. curly or straight, eye colour and shape of face and nose are combined. The people with these combination and other traits is categorise under specific geographical localities, that is called races. Besides phenotypic expressions, sex and age are also critical important in contribution to society. Nevertheless, the way others perceived and judge are influenced by biological or ethnic background.

In recent years, the reference to national origin, for example African or Asian is substitute to racial labels within and outside anthropology, however in 1950s the term ethnicity was proposed to avoid emotionally charged term “race”. Ethnicity refers to cultural factors, but the words ethnicity and race are interchangeably used. Forensic anthropologist, associates phenotypic criteria with person’s ancestry (especially in skeleton) to have practical applications. In forensic investigation, law enforcement frequently calls for forensic anthropologist assistance to identify skeletal remains. The identification must be as accurate as possible because the unidentified human remains are often those of crime victims. The most important variables in such identifications are the individual’s sex, age, stature and ancestry (racial and ethnic background).

There are various techniques, either metric or non-metric criteria for establishing broad population affinity (a likely relationship) for the individual. This chapter will review on the factors that contributes to human variations, footprint measurement techniques, literature review on; stature estimation from various footprint length and foot outline length measurements, body weight estimation from various footprint and foot outline measurements, sex estimation from footprint ridge density and reviews on cases related to footprints.

2.2 Human variations

According to Overfield (1995), humans were geographically separated along continental lines, oceans and mountains. Hence, the local populations were developed within the barriers. As the population isolated, the anatomical and physiological varies based on their gene pool, environments and the interaction between both factors. These variations obviously affect physical traits such as facial features, skin colour, hair texture and body size (magnitude of growth, i.e. adult height) and shape (body proportions) since it is often linked to an individual genetic ancestry (Eveleth and Tanner, 1990; Tishkoff and Verrelli, 2003). Forensic anthropologist uses the human variations to construct a biological profile of unknown identities to narrow down the pool of possible identifications. Ousley *et al.* (2009) stated that the global variation in body size and shape based on geographical pattern, allowed the statistical quantification to classify the group or population with high degree of accuracy. However, Roseman, 2004 and Ousley *et al.* (2009) reported that the absolute (100% accuracy) is impossible due to morphological overlapping both between and within populations.

In the past, prior to modern air travel, there was less migration and population were more stable (Overfield, 1995). However, nowadays population have continuously evolved and not remained static (Eveleth, 1986; Tiskoff and Verrelli, 2003) due to the increase in mobility and more open-acceptance of cross-cultural marriage. The regional variations in human groups that include growth, sexual dimorphism and individual variations facilitate the derivation of population specific formula to estimate age, sex and stature. The specific formulae are crucial because applying the formula to different population from the original reference population was found to decrease prediction accuracy (Ross and Konigsberg, 2002; Komar, 2003). Sarawak, East Malaysia comprises of about 40 subethnic groups and has no population specific estimation for stature, body weight and sex so far. The formula derived in this study has potential value and useful to solve crime cases involving Iban, Bidayuh, Melanau and Lun Bawang ethnics.

2.3 Genetic influences

Body size and proportions are also determined by the interaction between genetics and environment factors. As a child grow, the final size apparently due to the interaction between genes and environment and resulting to diversity in modern human populations. Silventoinen (2003) reported that the final adult size and shapes are controlled by the interaction of numerous genes. Preece (1996), Wei and Gregory (2009) and Silventoinen *et al.* (2008) suggested a child's final adult height is genetically determined. Eveleth (1986), Rona and Chinn (1986), Martorell *et al.* (1988), Eveleth and Tanner (1990) and Ulijaszek (1994) had highlighted the contribution of one gene causes the difference in growth curves between ethnic groups. Chen (1990b) stated that the combination of genetics and environmental differences affect the smaller size of Asian children (Malaysian) with relatively shorter legs compared to European ancestry.

Genetic variations relating to geographic worldwide patterning have been clearly demonstrated by modern technique in deoxyribonucleic acid (DNA) fingerprinting via genetic markers i.e single nucleotide polymorphisms (SNPs) and variable number tandem repeat (VNTRs) (Pritchard *et al.,* 2000; Rosenberg *et al.,* 2002; Bamshad *et al.,* 2003; Alloco *et al.,* 2007). The usage of SNPs and VNTRs gives accurate classification of individuals based on their ethnicity, as the DNA of individuals from the same continent tend to cluster together. According to Sommer (1992), the most important source of genetic variation is mutation, on average, 19 new mutations are estimated to occur in any one individual, but these genes will be missense or silent mutations with little or no functional significance.

Despite permitting more phenotypic variation, these mutations do not change normal anatomical and physiological functioning. Another two mechanisms that contribute to genetic variability are gene drift and gene flow. Gene drift happens because of random fluctuations in gene frequencies in small populations whereas gene flow occurs when people migrate to and settle in a different region from where they are born, which can change the gene frequencies in that particular population by introducing more variability (Tishkoff and Verrelli, 2003).

2.4 Environmental influences on human variations

Environment has considerable effects to the mean differences between and within populations. The major influence is physical environment involving climate and altitude. The environmental influence as a result of long-ranged adaptation differences in human body size and proportions (Ruff, 2002). Silventoinen (2003) has demonstrated that nutritional and diseases also significantly contribute to human variations.

2.4.1 Physical environment

Biological variations in humans occur as a result of climate and altitude factors under physical environment. Trinkaus (1981) and Ruff (1994; 2002) indicated that human's anatomy and physiology is adapted to surrounding environment for thousands of years, thus the variation is the result of natural selection. Lampl and Johnson (1993) and Lampl (2009) added a relative mechanism provides variation in timing and amplitude growth development whereby the pattern is adapted to withstand ecological conditions. Physiology integration between growth hormone (internal) and physical environment (external stimuli effects of gene expression) result in human growth and development (Lampl, 2009; Blangero, 2009). The relationship between external and internal stimuli was proven by Serrat *et al.* (2009) as they conducted an experimental study on mouse epiphyses that exposed to cold temperature had shown lower salute transport (which is important for cartilaginous growth) than the control mouse epiphyses.

The experimental mouse resulted with shorter limb as compared to control mouse epiphyses. This finding implies that human phenotypic variation in modern population is influenced by cultural adaptation to extreme environmental condition.

2.4.1(a) Warm and hot climate

Kleiber (1961) reported that heat production is proportionate to body mass, whereas heat loss is proportionate to body surface area. This statement was supported by Allen (1877) in the Allen's rule which stated that, endothermic animals that are mammals from colder climates usually have shorter limbs (appendages) than equivalent animals from warmer climate. This theory proposed that people who live in warmer environments generally have relatively longer limbs and narrower body to maximize heat loss for survival than those from cold environments (Trinkaus 1981; Ruff 1994; 2002). The adaptation to thermal stress explained by the tall lean proportions of the Nilotic peoples of East Africa and the lower stature of tropical rainforest inhabitants such as Mbuti (Hiernaux, 1974). The concept of larger surface area to body mass ratio to facilitate heat loss from sweating is called thermoregulation, thus in warmer climate, large variation of body size and proportion are significant.

2.4.1(b) Cold climate

Alexeeva (1980) and Endo *et al.* (1993) reported that individuals indigenous to colder climates increased in body fat and have broader upper body than individuals living in warmer climates. According to Bergmann (1847) in the Bergmann rules, latitude correlates with body mass which indicated that individuals at high latitude region are expected to be larger with smaller surface area to body mass ratio to prevent heat loss through skin. Endo *et al.* (1993) demonstrated that individual at colder climate has higher correlation between body size and caloric intake. In cold environment, increased food consumption helps to regulate body temperature. The theory of Bergmann rule contradicted to Holliday and Hilton (2010) findings on the body size and proportions of Inuit people. The authors found that the body size has shown no significant difference in body proportions from Europeans. The authors predicted the circumpolar group who live in extreme cold climate exhibit bodily proportion that are colder adapted such as foreshortened limbs and broadest pelvises. However, the circumpolar group did not show similar body proportion with North African (Holliday and Hilton 2010).

2.4.1(c) Altitude

The characteristics of broader upper limbs in cold climate dweller were noted by Alexeeva (1980) and Endo *et al.* (1993). The finding was also in agreement with Baker (1969), Eveleth and Tanner (1990) and West (2006) which demonstrated that individuals indigenous to high altitude having relatively enlarged chest and lungs as compared to low altitude dwellers. The broad chest could be due to the adaptation to high altitude impact and hence caused hypoxia for survival in cold environment. Haas *et al.* (1982) reported that the growth of well-nourished Bolivian infants also affected at high altitude as their recumbent length is significantly smaller (about 1 to 3 cm) in comparison to lowlanders from birth to 12 months old age. Despite of their smaller length, Haas *et al.* (1982) examined that highland infants had a higher percentage of body fat with larger skinfolds by the age of 3-12 months. Baker (1969) also found that the growth of children live in high altitude is slower and prolonged. However, Evelenth and Tanner (1990) reported that the children would attain final living height similar to their ethnic counterparts at lower altitude, which implies altitude does not actually affect adult height, but does have adaptation in physiological features.

2.5 Nutrition and diseases

One of the main factors that affect growth and final adult size are nutritional deficiencies and widespread of disease during childhood (Silventoinen, 2003). According to Eveleth and Tanner (1990), child is most at risk of the combination between malnutrition and infection is from birth to 5 years old of age. Bradley and Corwyn (2002) stated that body size does correlates with malnutrition and poor health of children from low socioeconomic families. The long-term period of under-nutrition during childhood and adolescence likely causes growth retardation and permanent effect on final size especially height. Stephensen (1999) indicated that the disease plague during childhood contributes to various ill effect since it can diminish appetite, impede nutrition absorption, nutrition losses, increase metabolic requirements or catabolic losses and impair transportation of nutrients to the target tissues.

According to Martorell (1980) and Alam *et al.* (2000), the most powerful cause of growth hindrance mainly in developing countries is diarrhoeal disease. In addition, inflammatory and chronic diseases such as congenital heart disease and heart failure have also been found to inhibit growth and final living height (Poskitt, 1993; Skerry, 1994; Furth *et al.*, 2002). The slow down growth in children can be restored to normal growth phase when they undergone catch up treatment that normally above normal growth velocity requirements (Prader *et al.*, 1963). In countries where nutrition is adequate the children will be treated with growth hormone deficiency (Tanner *et al.*, 1971; Hokken-Koelega *et al.*, 2001). Those countries with nutrition below the optimal intake have no capability to provide such treatment, hence the children may not be able to reach up to their potential stature.

2.6 Socio-economic status, urbanisation, smoking and other toxins

Eveleth (1986) suggested that human growth is directly or indirectly related to nutritional and health status. Based on epidemiological data, the world's population living under low socioeconomic conditions tends to have higher parasitic disease causes smaller body size (Crompton and Nesheim, 1982). On the other hand, urbanisation population i.e. Europe has larger body size and rapidly matured over the last hundred years (Eveleth and Tanner, 1990). In developed countries that have regular supply of food, clean water, health and sanitation services produced positive influence to the growth. Conversely, in developing countries the population may likely suffer from restricted growth due to rapid migration from rural area that causes population density increased and live in minimal facilities or services and institutions. Besides socioeconomic and nutrition, human growth is also affected by smoking and other toxins. This bad exposure is likely to affect developing foetus and toxin-sensitive young children than adults (Bearer, 2000). According to Schell *et al*. (2009), current investigation on the Akwesasne people (Native American) has shown evidence the negative effects of toxin from food chain on prenatal (i.e. impaired development of thyroid hormone regulation system) and postnatal (i.e. delayed sex maturation) development.

2.7 Secular trends in growth with reference to stature

According to Eveleth and Tanner (1990), children in past few decades have been growing taller and maturing at faster rate than before. Cole (2000) further added that an adult height also increased at a rate about 1 to 3 cm per decade. The changes in human growth and development are known as secular trend. Studies on human growth particularly stature have shown the adaptability of human in response to environmental changes. The adaptations are also resulted from the interaction between genetic and environmental conditions. Bogin (1999) and Padez (2003) stated that an increased in height among modern populations have been related to the raised standard of living and indirectly due to improved socio-economic living condition, better sanitary conditions, vaccinations and quality of food.

At 10th to 17th century, no significant changes in stature until at 20th century due to an increased in standard of living (Gustafson *et al.*, 2007). The data collected from 11 European countries have shown an increase in height between 1960 to 1990. The tallest mean height of 1.81 m was observed in Dutch population while the shortest height of 1.70 m found in Portuguese population (Schmidt *et al*., 1995). In some Scandinavian countries (Denmark, Norway and Sweden), Netherlands and Italy the populations elevated in height after 1990. However, Larnkjaer *et al*., (2006) found that the height of population in Belgium, Portugal and Spain continued to increase at a rate of 2 to 3 cm between 1990 to 2000. An increased in adult height was also reported for Chinese (Bi and Ji, 2005), Taiwanese (Pen-Hua *et al*., 2007), Mexican (Malina *et al*., 2004), Brazillian (Castilho and Lahr,2001; Silva and Padez, 2006) and South African population (Hawley *et al*., 2009).

Eveleth and Tanner (1990) indicated that an increase in leg length entirely caused the adult height to increased. This result was concordant to Takamura *et al*. (1988) and Zhang and Huang (1988) in their study on Japanese students. Tanner *et al*. (1983) also found extremely strong secular changes in height in Japan between 1950 to 1980. Conversely, Masuoka *et al*. (1999) revealed that there was little evidence of secular trend in bones of height of Japanese children between 1986 and 1996. In Western Australia, Blanksby (1995) reported that the average stature of males and females had increased by 4% and 2% respectively. Similarly, Chen (1990a) observed positive secular trends in height among Malaysian children born from 1980 to 1985.

2.8 Secular trends in growth with reference to body weight

Zhen Wang and Cheng Ye (2005) examined changes in body height and weight in children and adolescents in Shandong, China between 1939 and 2000. The authors found the increments in weight 7.5 kg for boys and 0.3 kg for girls, corresponding to 1.70 and 0.07 kg per decade. This finding was consistent with Aminorroaya *et al*. (2002) which stated an increase of 1 to 4 kg in weight of Isfahani female with age ranging from 6 to 18 years in 1997 as compared to similar study in 1975. In contrast, Krawczynski *et al*. (2003) observed the unstable secular changes in height and body weight in children and adolescents in Poznan, Poland, between 1880 and 2000.

2.9 Footprint measurement techniques

There are various methods used to analyse and interpret bare footprints from simple Overlay (DiMaggio Method) to linear techniques (Gunn Method, Reel and Rossi Method) as well as ridge density counting. All methods are described in the following subsections.

2.9.1 Gunn Method

This method was introduced by Dr. Norman Gunn in the early year of 1970. The idea on developing comparison process emerged as he was requested to perform comparison on an unknown footprint found at the scene with footprint of suspected perpetrator in his casework. According to Vernon (2006), Dr. Norman Gunn constructed various linear measurements on footprints to assist him to describe and compare footprint evidence. The linear measurement approach that he employed finally led him to successfully conclude the matching process. The mentioned approached consist of six measurements. Five measurements are drawn from rearmost aspect of the heel to the tip most of the five toes. The sixth line then is drawn across the widest part of ball of foot area as shown in Figure 2.1. The six-line measurements are used as basic form in complete footprint discovery. However, in the case of recovery of partial footprint, he also added new lines to strengthen evidence. The additional lines can be started from any existing of the basic line (reference points) measurement for complete footprint as illustrated in Figure 2.2. If necessary, further additional lines can be added as shown in Figure 2.3.

Figure 2.1: Basic Gunn Method

(Source: Dennis Wesley Vernon and John A. DiMaggio (2017). Forensic Podiatry: Principles and Methods. *CRC Press, Taylor & Francis Group*. Second Edition).

Figure 2.2: Gunn Method for Partial Footprint

Figure 2.3: Extended Gunn Method

(Source: Dennis Wesley Vernon and John A. DiMaggio (2017). Forensic Podiatry: Principles and Methods. *CRC Press, Taylor & Francis Group*. Second Edition).

2.9.2 Optical Center Method

The Optical Center Method was used by Royal Canadian Mounted Police in 1990s. According to Kennedy (1996, 2005), Kennedy *et al.* (2003, 2005) and Kennedy and Yamashita (2007), the Optical Center Method was part of long term study that similar with Gunn Method in the aspect of comparison lines drawn between various landmarks of the footprint. However, the source and the destination of connecting lines are started and ended with optical centers. The optical centers can be calculated via auto computer aided design 2010 (AutoCAD 2010) software or manually by placing the series of concentric circles over the features being examined. The mark then created as reference points as shown in Figure 2.4. Six measurements are obtained. Five separate lines are originated from optical center of the heel to the optical center of each toe. The sixth line is directly drawn across the widest part the ball of foot area with the absence of optical centers.

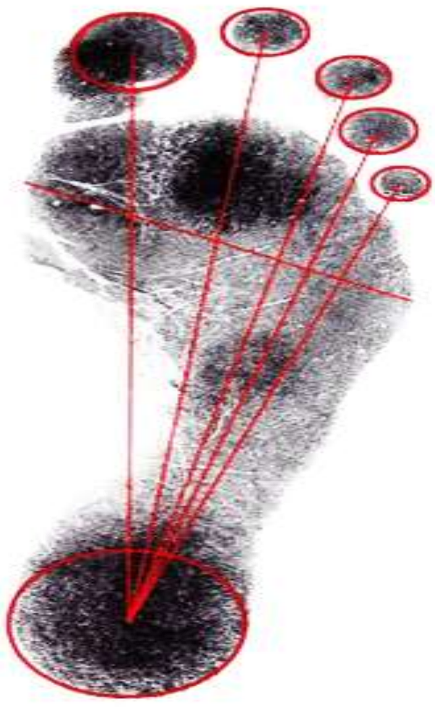

Figure 2.4: Optical Center Method

(Source: Dennis Wesley Vernon and John A. DiMaggio (2017). Forensic Podiatry: Principles and Methods. *CRC Press, Taylor & Francis Group*. Second Edition).

2.9.3 Reel Method

Reel (2012), through his work has critically evaluated literature related to previously available footprint measurements. Based on the evaluation studies, he invented a new pragmatic method for footprint comparisons. The method as shown in Figure 2.5 emphasised on the locality of the objective means at the rearmost of heel because even small variations in the point selected for measurements can lead to noticeable differences (Kennedy *et al.*, 2003). The objectivity was adopted from system of Podometrics Rossi (1992). The Podometric measurement systems was developed for the clinical description and categorisation of the human footprint. In this method, the intersection between the outermost lateral aspect part of the heel print with the lateral aspect of the ball of foot area and the innermost medial aspect of the heel with the medial aspect of the ball of foot area leads to the exact objectivity selected for measurement as portrayed in Figure 2.6. Another alternative for defining the rearmost aspect of heel is by aligning most lateral aspects of the fore-foot and the heel with one of vertical grid lines as depicted in Figure 2.7.