

WHAT IS THE IMPORTANCE OF AGE AT MENARCHE ON ADULT
HEIGHT RELATIVE TO OTHER KNOWN FACTORS?

by

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A Thesis submitted in partial fulfillment of the requirements
for the Honors in the Major Program in Political Science
in the College of Arts and Sciences
and in the Burnett Honors College
at the University of Central Florida
Orlando, Florida

Fall Term 2011

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ABSTRACT

Objectives: To analyze the association between age at menarche, as a measure of sexual maturation, and adult height from ten published studies.

Methods: Compared published measurements of age at menarche, adult height, and within-sample relationships observed in ten studies, for women from several societies and socioeconomic backgrounds, living in the 20th century,

Results: In these studies, early maturers were taller during pre-puberty, but had shorter adult height than later maturers. Late maturers experience a longer period of pre-pubertal growth and a delayed age of peak height velocity, leading to an extended overall time of growth, until adult stature was obtained.

Conclusions: Improved living conditions and energy balance increase childhood growth rate, and are associated with an earlier puberty, and shorter duration of growth. In developed countries duration of growth may play an increasingly important role in adult stature.

ACKNOWLEDGEMENTS

Thank you, Dr. McIntyre, thesis chair, for your patience and guidance over these past two and a half years. I appreciate all of the effort you put into molding me into a better writer, a better student and a better anthropologist.

Thank you, Dr. Dupras and Dr. Lieberman, committee members, for your input, advice, and a much appreciated extra third and fourth set of eyes.

Thank you, John Kacerosky, my dear husband, for supporting me throughout this endeavor.

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CHAPTER ONE: INTRODUCTION

HYPOTHESIS

What is the role of age at menarche in determining adult female height relative to other known factors? Biologically, holding all other factors constant, early puberty (early age of menarche) should result in shorter adult height. However, in the past century the average age at menarche has decreased while adult female height has increased. Research conducted on both the historical correlations and biological links between menarche and adult female height, shows that people are exposed to improved nutrition, improved sanitation conditions, and have overall good health will become taller adults than previous generations. In developed countries, once secular increase in height has reached a plateau, age at menarche should become a more important determinant of adult height. Therefore, I predict that the correlation between age at menarche and adult female height depends not only on physiology but also on social influences.

PHYSIOLOGY

In utero the human body experiences rapid growth to birth. From birth to the second year of life height growth decelerates sharply, remains constant throughout childhood, and then goes through another rapid growth spurt during puberty (Malina 1975, p. 9). Sex hormones such as estrogens and testosterone play an important role in human development by promoting the secondary sexual differentiation of the fetus and triggering the pubertal growth spurt (Leung et al. 2004).

Puberty is a transitional period from childhood to adulthood that consists of growth spurts, the appearance of secondary sexual characteristics, and the achievement of the body's ability to reproduce (Bogin 1999). Growth during puberty is characterized by the rapid growth of long bones (arms and legs) until the individual reaches peak height velocity. At this time the epiphyseal plate of the long bones begin to fuse, slowing and eventually stopping growth (VanDerEerden et al. 2003). At the histological level, this appears to be related to estrogens, including growth plate aromatase which increases the conversion of androgens into estrogen (Cutler 1997) and in turn accelerates growth plate senescence (Weise et al. 2001). By reaching puberty early, children hit peak height velocity at a younger age, which sets in motion an early stoppage of long bone growth, and a loss of potential growth in stature. Individuals who are late to mature experience extra pre-pubertal growth and a delayed age of peak height velocity, leading to an extended time of long bone growth (Biro et al. 2001). Until the epiphyseal plate has completely fused to the diaphysis, a long bone will continue to grow lengthwise. Therefore, the more time long bones are permitted to grow the longer they will be, creating longer legs and arms.

Within the past few years genes that control growth have been identified (Widén et al. 2010) and genetics do play a central role in human height. This thesis will not address forces of evolution such as natural selection, mutation, gene flow, and genetic drift (Stinson et al. 2000) and focus on polygenetic, ontogenetic, and proximate mechanisms, such as genes that may trigger early menarche (e.g. the CYP gene (Pei et al. 2008)), genes that affect child growth rate and epigenetic

factors (e.g. factors that influence gene expression). A prime example of how epigenetic factors play a role in adult female height is the Barker Hypothesis. This hypothesis found an association with between poor fetal growth and a small size at birth caused by maternal under-nutrition (Barger 2010). Babies who have a very low birth weight may also have a lower bone mass from birth to adulthood (Hovi et al. 2009). The low bone mass appears to have a correlation with shorter adult height (Leunissen et al. 2008).

OTHER INFLUENCES

Many studies have documented the correlation between age at menarche and adult height. The studies are diverse, varying in socioeconomic status, country of origin, age of participants, time in history, and duration of participation. These studies show a historical secular increase in adult height and a decline in pubertal age (Onland-Moret et al. 2005). Early age at menarche and taller adult height are presumably the combined results of improved nutrition and reduced infectious diseases, which allow children to grow at a more rapid rate during the early developmental stages of life.

Research on the correlations between menarche and adult height has focused on environmental factors such as diet (Thomas et al. 2001), which includes higher caloric, fat and fiber intake (Bratberg et al. 2006), higher body mass index (BMI) and weight of children under the age of 18 (He and Karlberg 2001), maternal (Windham et al. 2008) and adolescent (Cameron 2002, p. 179) smoking, fewer infectious diseases such as influenza, cholera, malaria and parasitic burdens (Rogol 2001), and higher socioeconomic status (Cole 2000) contributing to early puberty. On

the other hand, a poor living conditions such as crowded housing, (Abbas et al. 2008), inadequate waste removal, malnutrition (Leenstra et al. 2005), stress of war (Tahirović 1998), the frequency and duration of upper respiratory and gastro intestinal infections (Bona et al. 2002), hard physical labor during early childhood (Garnier et al. 2005; Thomas et al. 2001), cold climates, and high altitude hypoxia (Frisancho 1993) can contribute to an extreme delay of puberty.

METHODS

There are many studies which focus on the association between age at menarche and adult height using both longitudinal and retrospective approaches. I took an in-depth look at ten of these studies extracting pertinent information such as number of participants, participants birth year, age of participants during the study, and narrative result of the study, calendar years covered by the study, age at menarche for population within the study, average age of menarche for the population of the country of origin, geographical location of the study, socioeconomic status of participants, the mean adult height of participants, the correlation between age at menarche and adult height (or corresponding regression effects), and any stratification of results by race, age at menarche (early, intermediate and late) or other categorical variables. Multiple graphs were created to view different combinations of and correlations between data sets.

One of the more impressive studies is The EPIC Study (Onland-Moret et al. 2005). This research was conducted in the mid-1990s, lasted six years, and was comprised of 286,205 women from nine European countries. This study, as well as other related studies, shows that

early puberty produces shorter adult height and later puberty produce taller adult height. While the majority of these studies were conducted in countries with high socio-economic status (Europe and North America) (Biro et al. 2001; Bratberg et al. 2006; Frisancho and Housh 1988; Hardy et al. 2006; Okasha et al. 2001; Onland-Moret et al. 2005), the studies were conducted at different times and there are enough socio-economic differences to allow for an investigation of the major trends via a comparative analysis. By conducting a preliminary comparative analysis of the basic secular trends in these studies, we can see that even though the age at menarche seems to be dropping, there is an upward trend in adult height. The results are shown on the population-level association graph located in Appendix C.

A study conducted in Brazil clearly demonstrates the secular trend in a single country undergoing socioeconomic change. The results of this 1999 retrospective study of 1,940 females, ages 22 to 60, shows a decrease in average age at menarche from 12.61 to 12.15 years of age over the course of 30 years, while the majority of females (age 22 to 50) experienced an increase in adult height (do Lago et al. 2007). This coincides with Brazil's upward trends in wealth, poverty reduction, nutrition and public health conditions (Rogol 2001). However, do Lago et al. (2007) also noted a reversal in the association between age at menarche and adult height, from negative in older females to positive in younger females.

These different studies may use variables that appear to be similar, but are actually quite different, such as social class or socioeconomics. An example would be the Okasha et al. (2001) study where a woman's socioeconomic status was determined by her husband's level of

education. In contrast the Hardy et al. (2006) study determined socioeconomic status via the occupation of participant's father, with a non-manual occupation associated with a higher socioeconomic status and a manual occupation associated with a lower socioeconomic status. By taking into account the different operationalized approaches within each study, a comparative analysis was conducted with the hope to prove the association between age at menarche and adult height has become more positive over the time. The results of this comparative analysis will allow for a quantitative estimate of the true physiological effect of age at menarche, which is revealed as the secular trend plateaus in countries that have a wealthier economy and more access to resources, after which adult height can be more accurately predicted via the age at menarche.

CHAPTER TWO: PHYSIOLOGY

Human growth can be divided into two different stages in life; prenatal and postnatal. The prenatal stage of growth that occurs in utero averages 38 to 40 weeks in time. The postnatal stage of growth occurs after birth. Prenatal growth is divided into three stages; pre-embryonic, embryonic, and fetal (Malina 1975, p. 6). The pre-embryonic stage is a two week period that occurs after egg fertilization. This is a time of rapid cell division (mitosis), increasing complexity, and the development of the placenta and embryo. The embryonic stage begins after the two week pre-embryonic stage and lasts until the end of the eighth week. During this period, rapid growth and differentiation of cells occur. These cells organize into tissue, organs and systems of the body. The fetal stage begins after the eighth week and continues to occur during the remainder of the pregnancy. This is a time when the fetus experiences a rapid growth in size and mass. There is also the development of function in the tissues, organs and systems of the body. Eighty percent of our body's calcium, which will later ossify into bone, occurs during this time of growth, which happens mostly during the third trimester (Hovi et al. 2009).

The postnatal stage of growth can also be divided into three stages; infancy, childhood and adolescence (Malina 1975, p. 7). The infancy stage of growth occurs during the first year of life and is a time of rapid growth. The childhood stage of growth begins at year two and lasts until adolescence. During this time period growth and development is mostly a steady progression. The adolescence stage of growth occurs at different times for boys (age 10 to 22) and girls (age 8 to 19). This is the time period when most of our bodily systems grow into its adulthood form

and functionality. Growth accelerates during adolescent growth spurt, hits peak height velocity, decelerates, and finally by the end of adolescent growth, particularly of long bones, is terminated. However, not all growth has entirely ceased at the end of adolescent growth. The vertebral column will continue to grow until age thirty, increasing height on average to 3 to 5 millimeters (Tanner 1990, P. 19). Adult stature is finally reached once growth has been terminated.

Prenatal growth is measured by the length of the fetus, whereas postnatal growth, from the age of two years old, is measured by the standing height or stature. The velocity of growth is defined as the rate of growth over time. The velocity of growth of length, during the prenatal stage, is slow for the first two months and then steadily increases, reaching peak velocity of length at around 18 weeks (Tanner et al. 1988, p. 340). Compared to the velocity of growth of length, the velocity of growth in height, during the postnatal stage, rapidly decrease after birth and continues to steadily decrease until adolescence. During adolescence or puberty, growth is accelerated via a pubertal growth spurt.

Adult stature is established via a range of factors such as nutrition, environment, growth factors, genetic factors and hormonal factors. However, before one reaches one's final height three distinct endocrine phases of linear growth must happen (Appendix A). The first is a high rate of growth that starts at birth, rapidly decelerates around three years of age, and then a more slow deceleration of growth velocity up to the onset of puberty. During puberty one's longitudinal growth rate is increased until peak height velocity has been reached (VanDerEerden et al. 2003).

This growth spurt that occurs during puberty is caused by a combination of low estrogen levels and elevated growth hormone secretions causing longitudinal growth. Elevated growth hormones increase the number of cells in the body, through cell multiplication, and stimulating linear growth of the long bones (Malina 1975, p. 39). The stimulation of linear growth is achieved by chondrocyte proliferation and differentiation within the growth plate of long bones, such as arm and leg bones. Chondrocyte proliferation is the continuous development of cells (mitosis) within the connective tissue cell that occupies a lacuna or gap within the cartilage matrix, between the growth plate and the diaphysis, or shaft, of the bone. The growth, or epiphyseal, plate is located at each end or the metaphysis of a long bone and is comprised of cartilage (Appendix B). Estrogen has a biphasic effect on epiphyseal growth, with low levels causing maximal stimulation (Cutler 1997) and high levels causing stoppage of growth. Estrogen is also responsible for the development of secondary sexual characteristics during puberty, resulting in dramatic changes in one's physical development and the achievement of gender-specific body composition (Leung et al. 2004). Once peak height velocity has been reached, the velocity of growth rapidly decreases due to long bone and spine growth plate maturation, fusion and finally cessation of bone growth. The fusion of the growth plate is brought about by high levels of estrogen. This demonstrates that estrogen not only accelerates growth at low levels, but also inhibits longitudinal growth at high levels (VanDerEerden et al. 2003).

To understand how one reaches adult height, we need to understand how bones are formed. Human bone formation begins at the fetal stage. The second month of fetal development is

comprised of two essential processes; intramembranous and endochondral ossification.

Intramembranous ossification is the creation of new bone tissue, such as the roof of the skull and clavicle, directly from embryonic connective tissue without the presence of existing cartilage.

Intramembranous bone formation begins with an increased vascularity of tissue (containing vessels that circulate fluids) which allows transportation of nutrients thru the bone. Then the mesenchymal cells form osteogenic cells, which develop into osteoblasts. Clusters of osteoblasts, which build bone, lay down osteoid that calcifies to form spicules of spongy bone.

These spicules unite for form trabeculae, a honeycomb structure, which becomes compact lamellar bone. Endochondral ossification is the replacement of existing cartilage with bone tissue to create long bones as well as bones of the body's trunk. This early ossification during the fetal stage is known as the primary centre and while some bones may ossify from a single center, it is more common for ossification to occur at several small areas and form a new single center (Scheuer and Black 2000). Infants are born with approximately 450 separate ossification centers that later grow into a total of 206 adult skeletal bones (Baker et al. 2005).

Puberty occurs during the beginning of adolescence and is a characterized by the appearance of secondary sexual characteristics and the maturation of sexual organs. For girls, puberty marks the development of breasts, the growth of pubic hair, changes in body shape and fat distribution, body odor, acne, changes and maturation of the vagina, uterus, and ovaries, the beginning of menstruation, and the ability to ovulate. Menarche, marked by the first menstrual period, is just one of the many events in a complex biological process that transforms a girl into a woman (Sugar 1993, p. 4). There is no set time as to when menarche will occur, however studies have

shown that several factors can significantly influence age at menarche. These factors are general health and life style, nutrition (Thomas et al. 2001), physical activity, altitude level (Frisancho 1993), socioeconomic conditions, stress (Sinclair 1989, p. 170), and genetic parameters (Tanner 1990, p. 144). Even though surges of gonadotropins (stimulates ovarian function) and estrogens, which can reach ovulation magnitude, can be obtained prior to menarche, the synchronization of gonadotropins and estrogen cannot occur until menarche (Sugar 1993, p. 6). This synchronization influences ovulation, which then influences fertility.

As for what triggers menarche, there are two hypotheses that relate age of menarche to physical growth. The Frisch-Revelle hypothesis is contingent on body composition. It states that menarche is dependent on a critical minimum weight for height and fat distribution. Therefore girls who are well nourished and reach the average weight at menarche (101 to 103 pounds) will reach menarche at an earlier age than girls who are undernourished (Golub 1983). The other hypothesis is related to skeletal growth and states that for menarche to occur, girls must reach an appropriate stage of skeletal development. This means menarche will not occur until the female body has reached a mature height and the pelvis is of an adequate size to bear a child (Ellison 1982). Slow skeletal growth is related to poor nutrition and high altitude, resulting in late menarche. Accelerated skeletal growth is related to better nutrition and a healthy lifestyle, resulting in an early menarche.

When looking at why people vary in height genetically, Tinbergen's four categories of questions and explanations are good reference points. Three of the four categories are relevant to this

thesis. Therefore, the first category of function (adaptation) will be omitted, which focuses on natural selection. The second category is phylogeny which focuses on the evolutionary history of a trait. The third category is ontogenetic (development) which focuses on how something develops over an organism's life. The final category is proximate mechanisms which focus on how the trait works and what physical aspect of the body part in question causes it to function the way it does.

The human CYP17 gene is mapped to chromosome 10 and is used in the production of estrogen within the lipid precursor cells (Pei et al. 2008). The product of this gene is a steroid producing enzyme called P450c17. This enzyme supposedly has the ability to influence the production of estrogen. As stated previously low levels of estrogen accelerates growth and high levels of estrogen inhibits growth. Therefore it has been suggested that certain CPY17 genotypes could be a factor in age at menarche depending on the levels of estrogen the CPY17 gene produces. However, the conclusion of a meta-analysis performed by Yu-Fang Pei (2008) and her peers showed the CYP17 gene did not have a significant influence on age at menarche.

An epigenetic factor refers to heritable alterations in genes that affect the development of an individual but is not associated with a change in DNA sequence. A good example of an epigenetic factor is the Barker Hypothesis which associated poor fetal growth and a small size at birth with maternal under-nutrition. Babies who are born with a very low birth weight have a lower than expected bone mass. This low bone mass can persist throughout the life of the individual (Hovi et al. 2009). Low birth weight babies may also inherited alterations to growth

hormones and the hormone cortisol, which influences bone mass. Bone mass reaches a peak during adolescence and gradually declines from age 30 until death. The hormone alterations associated with low birth weight can lead to a lower peak in bone mass and a more rapid decline in bone mass after the age of 30. Leunissen et al. (2008) performed a study on the influence of birth size and body composition on bone density and correlated shorter adult height with a low bone mass.

Menarche does not occur until after peak height velocity has been reached (Sinclair 1989, p. 111). This is the time period within puberty where the growth spurt peaks and begins to decelerate. Pubertal growth spurt starts at the beginning of puberty is caused by an increase of sex hormones, such as estrogens and androgens (Ritzén et al. 2000). The cessation of growth of long bones occurs at the end of the decline in pubertal growth spurt and is caused partly by low concentrations of estrogen (Juul 2001). Girls who reach puberty early lose pre-pubertal growth and hit peak height velocity at a younger age, which sets in motion an early stoppage of long bone growth. Girls who are late to mature experience extra pre-pubertal growth and a delayed age of peak height velocity, leading to an extended time of long bone growth.

CHAPTER THREE: OTHER INFLUENCES

While the physiology of growth and development suggests that earlier menarche should result in shorter stature, this correlation is not always observed. If all variables are held constant adult height is directly affected by age at menarche. Females who have an earlier age at menarche are shorter in adult stature than females who have a later age at menarche. However, children do not grow up in a vacuum and there are many variables that have an effect on adult height. In this chapter we will focus less on how age at menarche affects adult height and more on the wide varieties of variables that affect adult height, as well variables that affect age at menarche. The secular trend in growth and development will be defined and discussed, as well as the variables that affect the duration of growth and the variables that affect the rate of growth.

Secular trend in growth is used to describe changes in growth and development over many generations within the same geographical location. Many studies involving European populations have noted the average adult height has increased from one generation to the next over the past 100 to 200 years (Ulijaszek et al. 1998, p. 395). At the same time, these studies have also shown the age at menarche has occurred at progressively younger ages. Improved environmental conditions, reduced family size, health care, (Eveleth and Tanner 1990, p. 191) better nutrition, controlled infectious disease through immunizations, higher birth weight, and a decline in premature babies are believed to be contributing factors in the upswing in adult height and early age at menarche. Eventually, both the increase in height and the decrease in age at menarche will slow down and then plateau (Eveleth and Tanner 1990, p. 206). The same types

of studies in underdeveloped populations have noted an opposite trend. These studies show a decreased adult height from one generation to the next and a delayed age at menarche. Declining living conditions, unsanitary waste disposal, and malnutrition are believed to be contributing factors for the decrease in adult height and later age at menarche.

Proper nutrition and a neutral energy balance are the two main variables that can insure a child will reach their potential height and not encounter a delay or slowdown in growth or sexual development. Proper nutrition should not be confused with supplemental foods. There have been many studies on the outcome of diets supplemented with either milk or protein and the results show no difference in adult height or age at menarche (Cameron 2002, p. 154). This does not mean a restriction of milk and protein within a diet will produce the same results. Proper nutrition requires an adequate supply of protein. Protein contains twenty two amino acids, of which thirteen our bodies can produce on its own, leaving nine essential amino acids that can only be acquired by eating protein rich foods. These nine amino acids are essential for human growth and if any one of these amino acids are absent, a stunting of growth can occur (Sinclair 1989, p. 158). Kwashiorkor is a condition that is brought upon by protein malnutrition and results in a slowing down of skeletal growth and a delay in puberty. Sufficient vegetable calorie consumption is another contributing factor to early age at menarche. A study was conducted involving 67 countries concluded the following conditions influence early age at menarche: adequate vegetable calorie consumption and a lower illiteracy rate which is influence by better living conditions (Thomas et al. 2001). A study of adolescent school girls from west Kenya concluded that the population of girls whose age at menarche was relatively late were more

malnourished than the girls whose age at menarche was relatively early (Leenstra et al. 2005). The study also discovered the malnutrition that was prevalent during the children's younger years was almost nonexistent during the time of late adolescence. The delay in menarche combined with a healthier late adolescence, prolonged growth by 1.5 to 2 years, allowed the girls to catch up from their incomplete growth.

Low socioeconomic status, overcrowded living conditions, poor sanitation and contaminated water can all contribute to the prevalence of infectious diseases, such as influenza and cholera, as well as parasitic diseases, such as malaria. Influenza is a viral infection that is transmitted from human to human via the tiny spicules of saliva, expelled from a cough or a sneeze, which hangs in the air or settles on surfaces for others to breathe in or touch. Overcrowded living conditions can cause the virus to spread quickly through the entire family or dwelling, as well and allow family members to re-infect each other. Rest, drinking lots of water and frequent washing of hands can inhibit the spread of influenza. If drinking water is contaminated, family members are then susceptible to bacterial infections, such as cholera. Cholera is associated with poverty and poor sanitation. It is a water born disease that occurs when drinking water has been contaminated with sewage, and children with cholera are inflicted with profuse diarrhea.

Malaria is also associated with profuse diarrhea and is contracted when a child is bitten by an infected mosquito. These infectious and parasitic diseases can have a short term or long term effect on adult height depending the duration and reoccurrence of the illness. The diseases can slow down growth during the illness. However, when health is restored, catch up growth occurs, bringing the child back to a normal growth curve (Eveleth and Tanner 1990, p. 191). If the

illness is chronic, the body does not have the ability to catch up and growth is permanently stunted, resulting in a shorter adult height. This is evident in a study of Guatemala children (Greene and Johnston 1980). The children in the study who were free of diarrhea for the first seven years of their lives were 3.5 centimeters taller than children who were inflicted with frequent bouts of diarrhea (Tanner 1990, p. 133).

Climate and altitude affect the human body's weight, height and body type. Individuals who live in colder climates and high altitudes tend to have an ideal cold climate body type of a thick torso with short limbs. The compact body and relatively small surface area of the shorter limbs allows the individual to more efficiently retain internal body heat and stay warmer in cold climates. Individuals who live in much warmer climates tend to have an ideal hot climate body type of a long lean torso with long limbs. The larger amount of surface area on a lean body with long limbs allows the individual to efficiently lose significant amounts of body heat into the environment by evaporative cooling or sweating. This is in conjunction with Allen's Rule that states warm blooded animals that live in geographically cooler locations have relatively shorter extremities than those who live in warmer locations and vice versa. These climate-adaptive characteristics are passed along in the form of genetics. Individuals who possess these characteristics for each type of climate have a higher possibility of survival, which leads to the potential of reproducing more often and therefore passing the genes onto their offspring (Tanner 1990, p. 144).

High altitude hypoxia is defined as a deficiency in oxygen at high altitudes. There have been many studies observing populations from high and low altitudes and its effect on adult height. In all of the studies high altitude hypoxia is the variable related to a delay in growth (Frisancho 1993). Malnutrition and high altitude hypoxia can retard growth; however they both have very different biological effects on the human body. Malnutrition decreases the amount of cytoplasm (the material between the nucleus and cell membrane) within a cell, whereas high altitude hypoxia causes a lesser number of total cells to be formed (Cameron 2002, p. 173). A study conducted by Stinson (1982) examined 323 European children, ages eight to fourteen, from middle to upper socioeconomic status and attending a private boarding school in Bolivia at altitudes of 3,200 to 3,600. The time frame that the children stayed at the boarding school varied. The study concluded that the children who lived at the high altitudes were six centimeters shorter than children of the same socioeconomic status, but living at much lower altitudes, suggests socioeconomic status does not play an important role in height when the only variable is high or low altitude. These children were also compared to local children of lower socioeconomic status and were found to be thirteen centimeters taller, suggesting that a low socioeconomic status plays an important role in delayed growth when it is the only variable. The same end result of stunted growth combined with a low socioeconomic status appears in children living in either high or low altitudes. Low socioeconomic status combined with high altitude causes more of a delay in growth than either variable on its own. However, the amount of time a child resides at high altitude significantly affected adult height. In the study, children with an average of the shortest times spent at a high altitude averaged out to be 3.75 centimeters taller than children who spend their whole life there (Cameron 2002, p. 174). An interesting

twist can be found in a study of Africa children who live in the mountains of Ethiopia. The Ethiopian children belonged to a higher socioeconomic status, receive better nutrition, and were taller than their African peers who live at a lower altitude, suggesting that a combination of a high socioeconomic status and better nutrition can outweigh the effects of high altitude on adult height.

Children living in an urban setting and who have sufficient food, healthy living conditions, adequate sanitation, education, easy access to clean water, recreation facilities and welfare are on the average taller than children who live in nearby country villages. However, if these conditions are absent from the urban areas then the opposite is true (Tanner 1990, p. 148).

Child labor cannot be viewed as a single variable. Other variables such as illiteracy and poverty are largely associated with child labor (Hawamdeh and Spencer 2003). Most likely poverty is the catalyst for a child to join the workforce and not attend school. Illiteracy is a direct result of a lack in education; an education the child could have received if stayed in school. Poverty is closely associated with poor nutrition. Poor nutrition can range from no food to food lacking in the appropriate calories, vitamins and nutrients that keeps a human body functioning properly. Poor nutrition is known to alter the ratio of lean mass to body fat, which then can delay age at menarche (Thomas et al. 2001). If a child is engaged in hard physical labor or long durations of labor, she is expending more energy than she would if attending school. If the expended energy exceeds the energy from calories consumed, the result is a negative energy balance (Garnier et al. 2005). Energy balance is when the energy in the form of calories that one takes in is equal to

the energy expended through physical activity. This negative energy balance can be responsible for lack of growth in height.

The number of siblings within a single family can impact adult height. Studies have shown the first born in a multi sibling family to be taller than their younger siblings, as they had the benefit of being an only child and access to more food prior to the births of their brothers and sisters. As a family grows in numbers, while keeping the socioeconomic status static, the food source divided among the entire family will result in less food consumption for each individual (Tanner 1990, p. 151).

Both maternal and adolescent smoking has a negative effect on human growth. Maternal smoking of twenty five or more cigarettes a day during mid pregnancy onto birth results in a baby with a low birth weight and a smaller size that persists into childhood (Ulijaszek et al. 1998, p. 303). A study examining the effect of heavy prenatal smoking was conducted by Windham et al. (2008) concluded a 1.9% decrease in height of children by age seven and a 5.3 months delay in age at menarche at adolescence compared to children of non-smoking mothers. Another study of postnatal growth of children whose mothers smoked during pregnancy conducted by Hardy and Mellits (1972) concluded a one centimeter difference in height after one year of growth. Butler and Goldstein's (1973) study yielded the same one centimeter difference in height of eleven year old children, when observing the affects of maternal smoking on postnatal growth. Over four thousand compounds have been indentified in tobacco smoke. These compounds can act as endocrine (hormone) disruptors, which effects both growth and

sexual development. Adolescents who smoke are exposing themselves to many toxic compounds such as metals (lead), pesticides (cyanide), polyaromatic hydrocarbons, and cadmium. Exposure to lead, cyanide and cadmium can hinder human growth (Cameron 2002, p. 179).

The stress of living through and experiencing the horrors of war can have many effects on the human body, one of which is a later age at menarche. Tahirovic (1998) ran a study in 1995, just months after the end of the war in Bosnia, on how the stress of war influenced age at menarche. The study involved 2,582 girls, ages eight to seventeen, who were deported from their home to live in a refugee camp. Over two thirds of the girls in the study experienced air raids and bombing, had their home and/or school attached or shelled, were exposed to armed combat, had a member of their family injured or killed, slept outdoors or slept in a shelter without their parents for more than three weeks, had inadequate food and water and were forced to relocate to a refugee camp. Over one half of the girls had to run while there was shooting going on around them and thought that they would be killed. A little over one third of the girls witnessed someone being killed. Tahirovic (1998) concluded the negative influence of psycho-emotional stress brought about by war delayed age at menarche.

Psychological stress can inhibit growth, if exposed for long periods of time. A study was conducted on orphans in post war Germany to prove the positive effects of better nutrition with food supplements. To the surprise of the researchers the growth of the children from the orphanage that received supplemental food were falling behind the children of the control

orphanage that receive no supplements. The researchers discovered a superintendent at the orphanage was not a pleasant person and was inflicting severe emotional stress onto the children as they ate. It was concluded that this stress inhibited the children's growth (Sinclair 1989, p. 170). This type of psychological stress on children affects the secretion of growth hormones. If stress is experienced for extended periods of time, a child's adult height will be impacted. However, if the stress is removed, the secretion of growth hormone will return to normal, followed by catch up growth (Eveleth and Tanner 1990, p. 204).

There are many studies that suggest children who are exposed to over nutrition experience an accelerated linear growth and mature earlier than others. Bratberg et al. (2006) ran such a study involving 1,605 Norwegian adolescents researching how the combinational influence of early menarche and body fat affected adult stature. Their findings concluded females with a heavy body mass and an early age at menarche were taller in stature than leaner females with the same early age at menarche. He and Karlberg (2001) studied 3,650 children born in Sweden, and reported similar conclusions as Bratberg et al. (2006). The study showed children who reached peak height velocity at eleven and a half years or earlier and were over nourished (had a high body mass index) were taller than children within the same peak height velocity age group and a lower body mass index. However, these same children were shorter than any of the children (over nourished, nourished, or under nourished) who reached peak height velocity at twelve and a half years or later (He and Karlberg 2001).

Environmental toxins such as pollution from hazardous waste are another variable in stunted growth. Love Canal is a small town located in upper New York State. An elementary school and approximately one hundred residential homes were built on top of a hazardous chemical land field containing twenty one tons of toxic chemicals. These chemicals leaked into the water, soil, air, sewers, and basements of residential homes. Compared to children of the same socioeconomic status but living in a different geological location, the children who were born and raised in Love Canal were significantly shorter in stature than those who lived in an area free of environmental toxins (Ulijaszek et al. 1998, p. 344).

One's socioeconomic status is a catalyst for multiple independent variables. Each of these variables has the ability to influence early to late menarche, as well as short to tall adult stature. A low socioeconomic status can hinder access to food supplies, which can lead to malnutrition. Children in a low socioeconomic status could be required to endure hard physical labor to supplement their family's income. The combination of malnutrition and physical labor can contribute to a negative energy balance, where more calories are expended than taken in. These children who are working cannot attend school and may become illiterate. Children in a low socioeconomic status are subjected to poor living conditions, such as overcrowding, no access to clean drinking water or proper sanitation, little to no health care, exposure to infectious diseases and chronic illnesses. All of these variables associated with a low socioeconomic status are related to a late age at menarche and/or a shorter adult stature. On the other hand a high socioeconomic status can give one access to better nutrition and the availability of a more abundant supply of food, enabling children to consume the right kinds of food, including protein

and vegetable calories. Children in a high socioeconomic status have access to better living conditions, which gives them access to clean drinking water, uncontaminated food, good sanitation systems and health care, all of which enable a child to stay healthy during years of growth and development. Children in a high socioeconomic status have the means and time to attend school and acquire an education. They are not forced into hard physical labor or made to expend more calorie energy than the amount of calorie energy taken in, giving them a neutral energy balance or even a positive energy balance which can lead to over nutrition. All of these variables associated with high socioeconomic status are related to an early age at menarche and/or a taller adult stature via a more rapid growth, in contrast shortening of the duration of growth that result from earlier menarche.

CHAPTER FOUR: MATERIAL AND METHODS

This thesis relies on published results from prior studies, articles, and books that included assessments of age at menarche and adult height from the same sample of women. All information on this subject was gathered via searching articles and publications pertaining to age at menarche and adult height. Resources such as the UCF on campus library, the public library, Amazon's new and used book department, books and articles loaned or provided by my thesis committee chair, general internet searches, and UCF's on-line database for articles and other information were extensively used to research my topic.

University of Central Florida (UCF) has wide range of journals and articles within its on-line database. Advanced searches from the Medline-PubMed and the Web of Science databases were used for this thesis. The following keywords and phrases were used to locate articles on correlations between age at menarche and adult height.

- Adult height
- Adult stature
- Age at menarche
- Correlations
- Cross-sectional studies
- Development
- Early puberty
- Estrogen and androgens
- Final height
- Growth studies
- Health
- Human development
- Longitudinal Study
- Peak height velocity

- Puberty
- Pubertal growth spurt
- Study
- Velocity of growth

Many articles involving studies that reported the association between age at menarche and adult height were found. Ten of these studies were retained for use in the thesis (Appendix E). These studies were composed of two types of research: longitudinal and retrospective studies. One half of the studies were longitudinal and the other half were retrospective. Longitudinal studies are studies that observe the same participant through different stages of their life (Tanner 1990, p. 10). The Bratberg et al. (2006) study ran for six years and the participants visited the researchers for measurements once when they were 12 to 16 years of age and once again when they were 16 to 20 years of age. The Brio et al. (2001) study ran for ten years and the participants visited trained researchers once a year for measurements. The St. George et al. (1994) study ran for eighteen years and the participants meet with the researchers repeatedly over the eighteen year period for data collection. The Carrascosa et al. (2008) study ran for twenty three years and the participants met with the researchers one to three times a year for 18 to 19 years for measurements. The longest longitudinal study conducted by Hardy et al. (2006) ran for fifty three years and the researchers maintained regular contact with the participants over the 53 years to collect measurements. To observe the exact time of age at menarche, two of the five longitudinal studies started to record data with the birth of the subject. The other three began their studies with three year olds, nine to ten year olds, and twelve to sixteen year olds (Biro et al. 2001; Bratberg et al. 2006; St George et al. 1994). Retrospective studies are studies where the participant self reports her age at menarche. This type of study is considered to be a fairly

accurate measure of pubertal age, because as an important event in life, ones age at menarche is highly remembered, even when recall was requested from the elderly (Madrigal 1991). However, inaccuracies such as remembering the exact point in time or irregular first menstruations could lead to underreporting the actual age it occurred (Stattin and Magnusson 1990). All of the retrospective studies used questionnaires to record age at menarche asking the questions: Do you recall the start of your menstrual cycle? At what age did you get your first period? What is the age (in years) at which your first regular menstrual period occurred? All but one of the retrospective studies used clinical exams to record adult height, sitting height and or weight. A wide variety of participant age ranges were used in the retrospective studies, with the small span from ages eighteen to twenty one and the largest span from one to seventy four years of age. The recall intervals for all of the studies were between five and sixty years, with most of the studies having some of the participants fall into a recall interval over thirty nine years. Must et al. (2002) found that recall of age at menarche for women with a recall interval of one to thirty nine years was generally quite good, both in precision ($r = 0.79$) and accuracy (mean error (recalled – original) = -0.08 years).

All ten studies were performed in the 20th century, except for one that ran a follow up in the early 21st century. The studies involved females from countries all over the world including Barcelona, Brazil, Denmark, France, Greece, Germany, Italy, Netherlands, New Zealand, Norway, India, Scotland, Spain, Sweden, UK, and USA. The number of participants in each study varies from as small as 115 participants to as large as 286,205 participants. Only data from the female participants were used in this thesis. The participant's year of birth was reported to be

as early as 1904 and as late as 1983. Most of the studies used a multi-year range of birth years. However, one study used the short time frame of a single week in the month of March 1946. Two studies ran follow-up sessions with their participants. Six of the studies included females from diverse socioeconomic levels. Two of the studies included only middle income females, one of the studies used females from unknown socioeconomic background, and one of the studies used females from the same socioeconomic background, but does not disclose the level of socioeconomic background. Seven of the studies derived data from internal and external surveys such as: the Young-Hunt 1 & 2 studies, the Pro-Health Study, the National Health and Nutritional Examination Survey I (NHANES I), the MRC National Survey of Health and Development (NSHD), the University of Glasgow health checks, the European Prospective Investigation into Cancer and Nutrition (EPIC), the Dunedin Multidisciplinary Health and Development Study.

All of the studies measured each participant's weight in kilograms and adult height in centimeters. However, many other measurements were taken in each study. The other measurements included: hip and waist circumferences, waist-to-hip ratio, leg length, leg-to-trunk ratio, sitting height, upper arm circumference, BMI, and subscapular skin fold thickness (SST), as well as skin fold thickness for biceps, triceps, subscapular, suprailiac and medial calf. Many of the studies were adjusted for confounding factors, such as, birth length, birth weight, placental weight, gestational age, birth order, number of siblings, mother's age at 1st pregnancy, parental height, parental level of education, participant level of education, manual or non-manual working

background, blood pressure, smoking, and alcohol consumption. Blood samples were taken for one study.

Not all of the studies contained the same exact type of information. In particular, studies stratified analyses in a variety of ways. For example one study divided the participants into white and black groups, while another study only used white participants. One study divided the participants into groups that included women who were born before 1945 and women who were born after 1945, to calculate the effects of WWII. In one study the mean height of females was separated into two categories (low waist circumference and high waist circumference) for each group of early, intermediate and late menarche ages. In all of these cases data was extracted for each strata separately. Four of the studies provided the average birth year, while all ten studies gave the average age of the participants during the study. The participants' average birth year could be calculated by subtracting the age of the participants from the year of the study. Many of the studies divided age at menarche into categories of early, intermediate, and late. Most used the lowest quintile, 15% to 20%, of age at menarche to define early menarche and the highest quintile, 80% to 85%, of age at menarche to define late menarche. If age at menarche was reported in categories, but the average age at menarche for the population within the study was not given, the weighted average age at menarche was calculated by adding all of the multiplied numbers together and then divided by the total number of participants. This calculation was performed on nine out of the ten studies. The midpoint calendar year at menarche was calculated for all ten of the studies by adding the average age at menarche for the study sample to the average birth year. Adult height was treated similarly to age at menarche, with weighted average

being used in some cases. This equation was repeated to find the mean height for females with intermediate and late maturational timing. A regression effect was calculated, using the year of birth as a continuous variable, to investigate the existence of secular trends in age at menarche. If the regression effect was not provided by the study, as was the case in half of the studies, height was stratified by categorical age at menarche; a pseudo-slope was calculated from the highest to the lowest category of age at menarche.

A reference spread-sheet was created by inputting bibliographic information, average (or weighted average) age at menarche, adult height, regression effect, and calendar year for each sample stratum (Appendix C). A smaller list of articles by title, author and reference name was also created and imported into a spread-sheet (Appendix E). Data from the ten articles were examined and plotted into graphs. The regression graph (Appendix C) was created to verify the importance of age at menarche on adult height. This graph contains the correlation between age at menarche expressed in years and adult height expressed in centimeters, with a regression line. The secular trend graph (Appendix D) was created to verify the changes of the secular trend over the past hundred years. This graph contains the correlation between the regression effect of age at menarche on adult height and the midpoint calendar year of menarche per study, with each plotted point showing the number of participants within the study. All graphs were created via Microsoft Office Excel 2007.

CHAPTER FIVE: RESULTS

All but one study found that age at menarche has an effect on adult height, with adjustments for other known factors or variables. For women whose birth year is after the mid to late 1940s, adult height is shorter for earlier maturers than late maturers. These women as girls were taller during the early ages of their life, but gained the least amount of height overall and were shorter than late maturers as adults. Females from two studies who were taller than their peers at age 7, also reached menarche earlier than their peers (Hardy et al. 2006; St George et al. 1994). However, by age 15 these girls were overtaken in height by later maturing girls. Girls in the do Lago et al. (2007) study that were born after the late 1940s and who reached menarche later, showed an increase in adult height for each additional year of pre-pubertal growth. As a result of WWII, severe famine affected growth in women from the Netherlands and Germany. Women from Greece also endured the repercussions of famine until 1949 due to the Greek Civil War which followed WWII. For these women, who survived the famine and may have endured malnutrition and other unfavorable conditions for growth, each additional year earlier at menarche was associated with a reduction in height of about 0.5 centimeters (do Lago et al. 2007; Onland-Moret et al. 2005). The results from the Carrascosa et al. (2008) study were a direct inverse from the other nine studies. Carrascosa's results showed girls with early pubertal growth spurts to be taller than girls with intermediate or late pubertal growth spurts. Carrascosa et al. (2008) believes adult height is not influenced by age at menarche, but is primarily influenced by genetics.

Each of the ten studies included results from other measurements that were taken during the course of the study. The majority of the studies reported results for the effects of age at menarche on pre-pubertal or adult weight and BMI. Four of the studies reported that girls who had a higher BMI and were heavier than their peers experienced menarche at an earlier age (Biro et al. 2001; Hardy et al. 2006; Okasha et al. 2001; St George et al. 1994). Two more studies reported that early maturers had significantly higher weights than late maturers (Frisancho and Housh 1988; Sharma et al. 1988). However, Carascosa et al. (2008) showed no statistical differences in the values of BMI either before puberty or in adulthood among pubertal timing groups.

The results from analysis of other factors show leg length increasing with increasing age at puberty and vice versa (Hardy et al. 2006; Onland-Moret et al. 2005). Both birth order and the number of siblings within a family were positively associated with age at menarche (Okasha et al. 2001). Daughters of tall mothers had later age at menarche (St George et al. 1994). Girls with a high waist-to-hip ratio at early adolescence and an early age at menarche were 3.6 cm taller in late adolescence than girls with low waist-to-hip ratio at early adolescence and an early age at menarche (Bratberg et al. 2006).

In the past two centuries several European populations have seen a decrease in age at menarche and an increase in adult height, following the secular trend in growth. The results from these ten studies conform to this secular trend, as seen in Appendix C. This chart plots the average age of menarche with the average adult height of all the participants within each study. This chart does

not show that girls with an early age at menarche are taller than girls with later age at menarche. It is simply stating that each population within each study on average has an early age at menarche as well as a taller adult height. Appendix D addresses the question of individual-level effects by plotting the regression effect (beta coefficient) for the individual-level associations within each study. This chart shows that over the past hundred years, for the most part, age at menarche is on the decline while adult height is on the rise. In summary, each additional year of age at menarche is associated with an increase in adult height (do Lago et al. 2007). Girls with an early age at menarche have a shorter adult stature than girls with a later age at menarche. If these girls grow and develop in an environment that is conducive to positive growth, then each year the overall average age at menarche will decrease, while the overall average adult stature will increase. Even though early maturers are shorter than late maturers within the same cohort, they are taller than those of earlier cohorts, who matured later on average, and will be shorter than those of future years, who will mature earlier until, that is, age at menarche and adult height plateau.

CHAPTER SIX: DISCUSSION

This thesis confirmed that adult height is correlated with age at menarche. The majority of articles reported by investigators confirm a statistically significant association of age at menarche with adult height, with early maturers having a shorter adult height and later maturers having a taller adult height.

Other factors were evaluated within the studies showing heavier children, with increased body fat, grew faster reaching menarche earlier, which shows the association between early maturers and height can be modified by the level of fatness in early adolescence; which may be a result of over nutrition (Bratberg et al. 2006). Early maturers have shorter leg lengths than later maturers, but longer leg lengths than early maturers of past decades. This may be due to improved growth conditions during the secular trend resulting in rapid growth during adolescence (McIntyre 2011). Women who were born during or just after WWII were consistent with the secular trend of an early age at menarche, but had a shorter adult height, mostly likely due to famine and malnutrition.

Some of the studies and articles used in this thesis had a number of limitations. Three of the studies had a very small sample size (Carrascosa et al. 2008; Sharma et al. 1988; St George et al. 1994) and the small effect size combined with non-random sampling could yield extreme results. The population sample for all of the studies may not represent a true random subset of the population. Some of the studies used population samples from the same or closely related

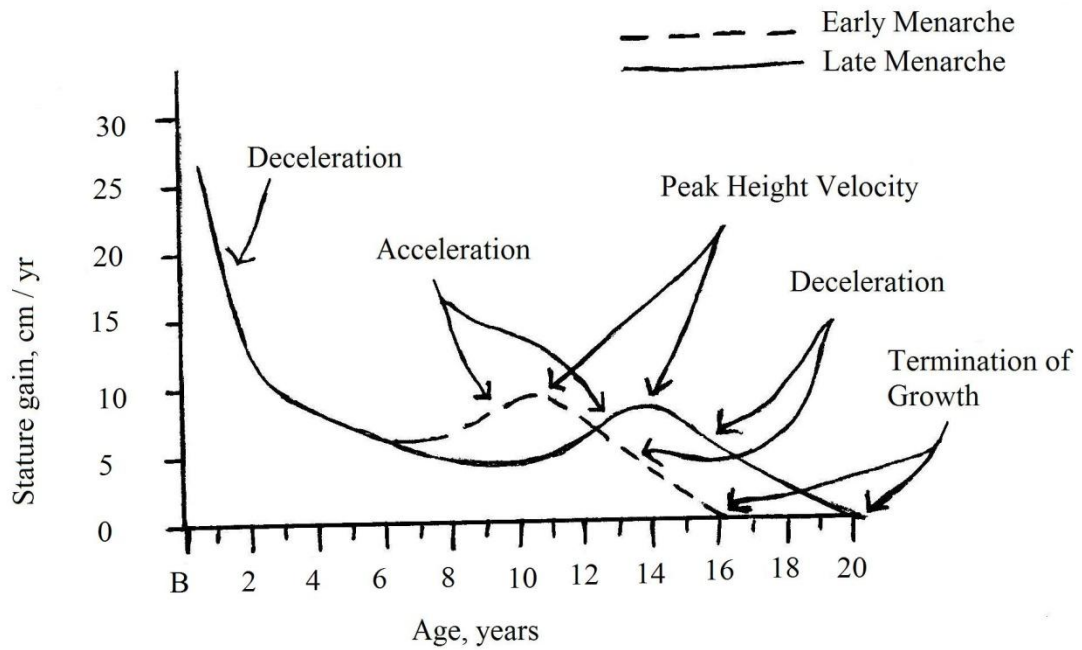
socioeconomic background and therefore a broader view of the effects of very low to very high socioeconomic differences may not have been evaluated. Most of the studies used European populations where improved living conditions have been available for many years. Very few third world or deeply economically deprived populations were studied. An accurate representation of diverse levels of living conditions cannot be provided using this data. The questionnaires used within the retrospective studies may have inaccuracies, such as in the reporting of age at menarche as well as over estimation of height (Onland-Moret et al. 2005) and underestimation of weight. Women whose recall interval was 39 years had a mean error of recall of 2.4 months. For all practical terms, if one is dealing with groups rather than individuals this mean error is insignificant and accurate enough for anthropological purposes (Damon and Bajema 1974). Accuracy of recall increases as the recall interval decreases. Restricting the ages of women to a period of 5 to 10 years after menarche could ensure a more accurate recall of age at menarche (Damon and Bajema 1974).

For future studies information about childhood nutrition and illness should be evaluated as potential modifier of the association between growth duration and adult height. Growth patterns of developing countries could be analyzed (Allal et al. 2004). Childhood growth rates from more diverse socioeconomic backgrounds could be assessed for differences. Height at menarche could be recorded to see how close in height both early and late maturers were at menarche. The use of longitudinal study design over a retrospective study design would strengthen the results by the use of professionals to take multiple measurements of height for the duration of the study. The use of standardized anthropometric measurements, a high attendance rate, a larger number of

diverse participants, and way to evaluate ones socioeconomic status could also strengthen future studies.

APPENDIX A: A VELOCITY CURVE

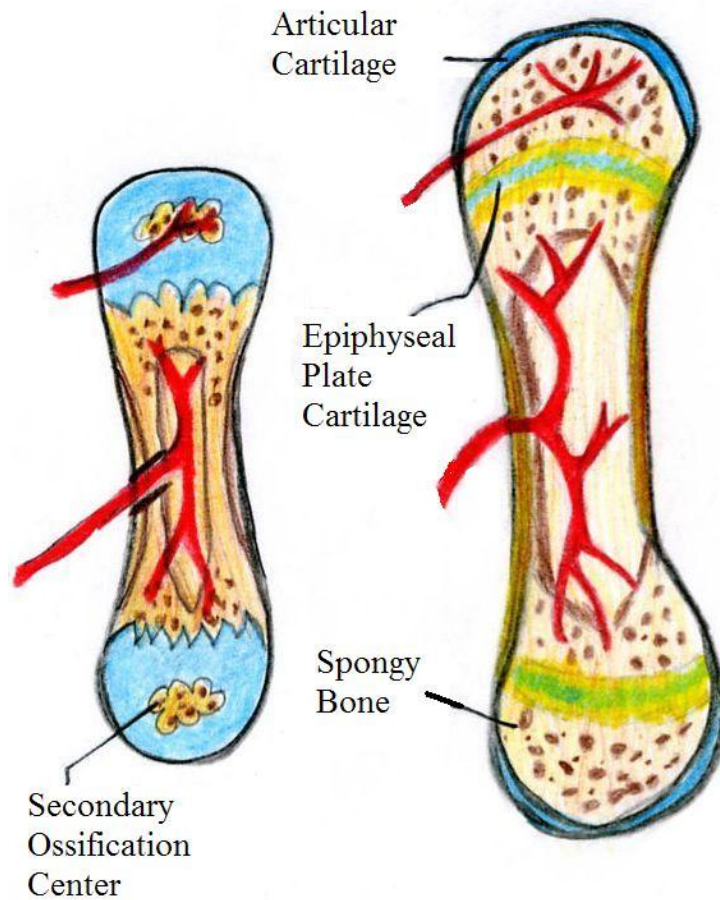
APPENDIX A: A VELOCITY CURVE



Appendix A - A velocity curve indicating different phases of growth rate for stature of girls with early or late menarche

APPENDIX B: BONE CHART

APPENDIX B: BONE CHART



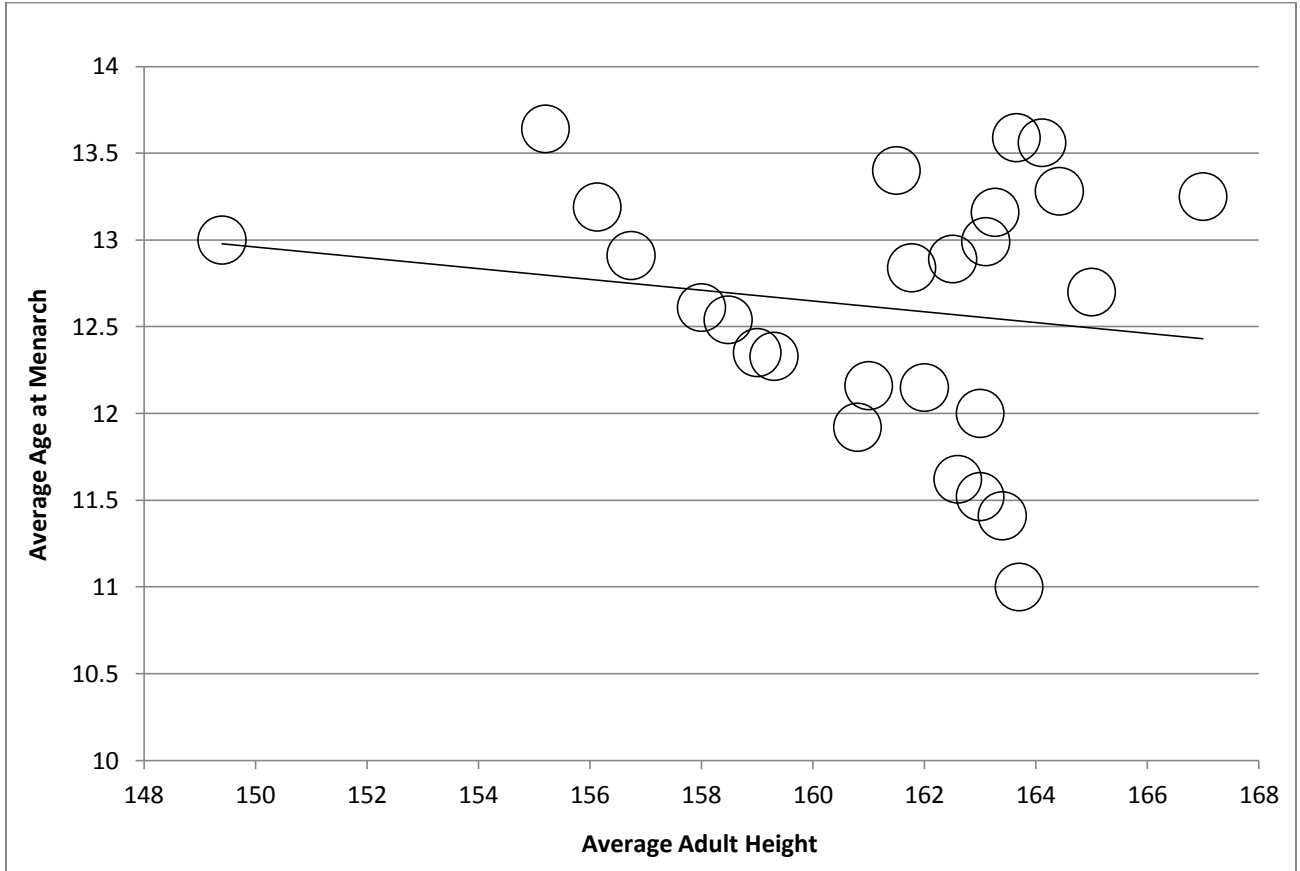
Appendix B –

An image identifying a secondary ossification center within a long bone of an infant

An image identifying an epiphyseal plate within a long bone of a child / adolescent

APPENDIX C: POPULATION-LEVEL ASSOCIATION GRAPH

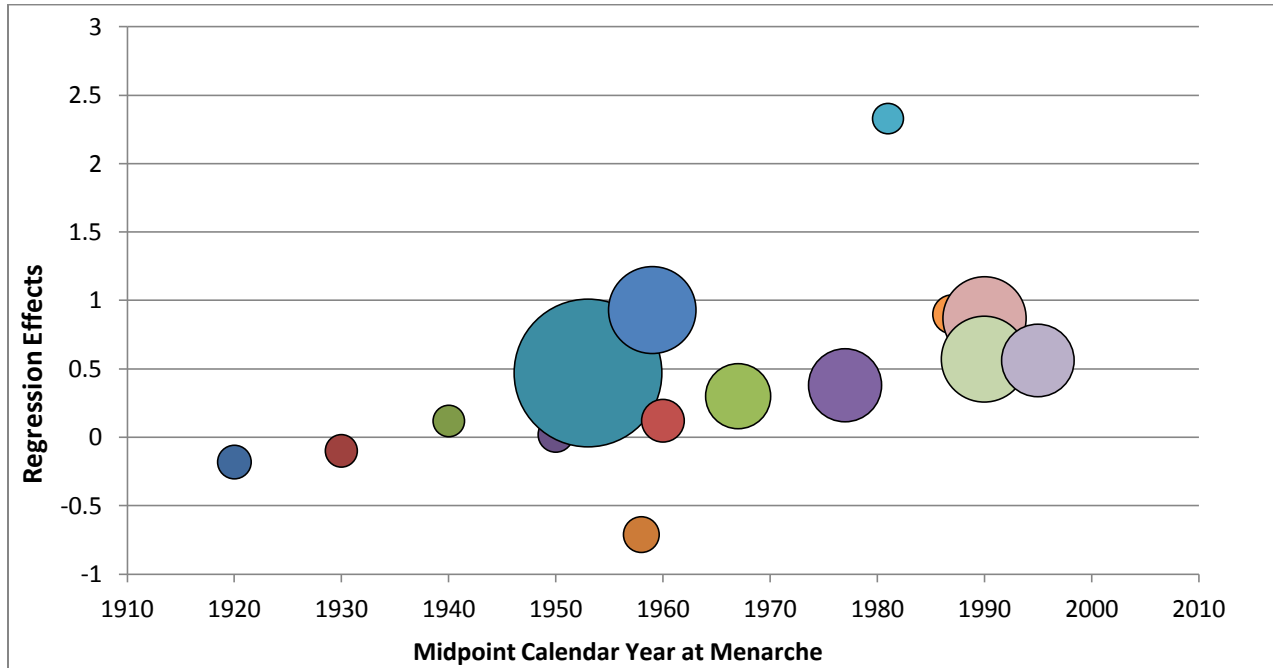
APPENDIX C: POPULATION-LEVEL ASSOCIATION GRAPH



Appendix C – Association between sample average age at menarche and height

APPENDIX D: INDIVIDUAL-LEVEL ASSOCIATION GRAPH

APPENDIX D: INDIVIDUAL-LEVEL ASSOCIATION GRAPH



Appendix D – Individual-level association between age at menarche and height by calendar year of study.

APPENDIX E: TEN MENARCHE STUDIES

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Title of Study	Authors of Study
Impact of timing of pubertal maturation on growth in black and white female adolescents: The National Heart, Lung, and Blood Institute Growth and Health Study (Biro et al. 2001)	Frank M. Biro, MD, Robert P. McMahon, PhD, Ruth Striegel-Moore, PhD, Patricia B. Crawford, DrPH, RD, Eva Obarzanek, PhD, MPH, RD, John A. Morrison, PhD, Bruce A. Barton, PhD, and Frank Falkner, MD, FRCP
Combined influence of early sexual maturation and central adiposity on subsequent stature (Bratberg et al. 2006)	Grete H. Bratberg & Tom I. L. Nilsen & Turid L. Holmen & Lars J. Vatten
Influencia de la edad de inicio del brote de crecimiento puberal en la talla adulta (Carrascosa et al. 2008)	Antonio Carrascosa, Laura Audía, Joan Bosch-Castañea, Miguel Gussinyea, Diego Yestea, María Ángeles Albisua, María Clementea, Ángel Ferrándezb y Luis Baguerb
Associacao entre idade da menarca e estatura definitiva no estudo pro-saude (do Lago et al. 2007)	Marcos Junqueira do Lago, Eduardo Faerstein, Rosely Sichieri, Claudia S. Lopes, Guilherme L. Werneck
The relationship of maturity rate to body size and body proportions in children and adults (Frisancho and Housh 1988)	A. R. Frisancho and C. H. Housh
Age at puberty and adult blood pressure and body size in a British birth cohort study (Hardy et al. 2006)	Rebecca Hardy, Diana Kuh, Peter H. Whincup, and Michael E. J. Wadsworth
Age at menarche: secular trends and association with adult anthropometric measures (Okasha et al. 2001)	M. Okasha, P. McCarron, J. McEwen, and G. Davey Smith
Age at menarche in relation to adult height: the EPIC study (Onland-Moret et al. 2005)	N. C. Onland-Moret, P. H. M. Peeters, C. H. van Gils, F. Clavel-Chapelon, T. Key, A. Tjønneland, A. Trichopoulou, R. Kaaks, J. Manjer, S. Panico, D. Palli, B. Tehard, M. Stoikidou, H. B. Bueno-De-Mesquita, H. Boeing, K. Overvad, P. Lenner, J. R. Quiro´s, M. D. Chirlaque, A. B. Miller, K. T. Khaw, and E. Riboli
Age at menarche in relation to adult body size and physique (Sharma et al. 1988)	K. Sharma, I. Talwar, N. Sharma
Body size and the Menarche: the Dunedin Study (St George et al. 1994)	Ian M. St. George, M.D., Sheila Williams, B.Sc. (HONS), and Phil A. Silva, Ph.D.

APPENDIX F: DATA SETS FROM TEN STUDIES

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Data Sets from Studies Used to Access Age At Menarche								
Data SubSet from Studies Used to Analyze Slop of Regression								
Citation	Average Age at Menarche	Average Adult Height	Pseudo Slope	Sample Size	Longitudo or Retrospective	Years of Birth	Year Study was Conducted	Country
Brio et al. 2001	White girls 12.7	White girls 165	White 0.87	2256	Longitudal	1977 to 1978	1987 to 1997	United States
	Black girls 12.0	Black girls 163	Black 0.57					
Bratberg et al. 2006	13.25	167	0.57	834	Longitudal	1980 to 1983	1995 to 1997 / Follow up 2000 to 2001	Norway
Carrascosa et al. 2008	11	163.7	0.62	115	Longitudal	1978 to 1982	1978 to 2001	Barcelona
do Lago et al. 2007	12.61	158	-0.71	1940	Retrospective	1939 to 1948	1999	Brazil
	12.35	159	0.3			1949 to 1958		
	12.16	161	0.38			1959 to 1968		
	12.15	162	0.9			1969 to 1977		
Frisancho and Housh 1988	12.33	159.3	-0.18	976	Retrospective	1904 to 1913	1971 to 1973	United States
	11.92	160.8	-0.10			1914 to 1923		
	11.62	162.6	0.12			1924 to 1933		
	11.41	163.4	0.02			1934 to 1943		
Hardy et al. 2006	13.4	161.5	0.93	1197	Longitudal	1946	1946 to 1999	Britain
Okasha et al. 2001	12.99	163.1	0.47	3433	Retrospective	1919 to 1952	1948 to 1968	Glasgow, Scotland
Onland-Moret et al. 2005	12.84	161.77	0.44	70,913	Retrospective	1921 to 1956	1992 to 1998	France
	12.54	158.48	0.5	31,559		1920 to 1962		Italy
	12.91	156.74	0.43	25,241		1925 to 1961		Spain
	12.89	162.51	0.37	44,025		1918 to 1963		UK
	13.28	164.42	0.37	25,414		1924 to 1962		Netherlands
	13.19	156.13	0.13	14,428		1920 to 1964		Greece
	13.16	163.27	0.37	29,669		1926 to 1963		Germany
	13.59	163.65	0.26	16,699		1923 to 1950		Sweden
	13.56	164.11	0.37	28,257		1929 to 1947		Denmark
Sharma et al. 1998	13.64	155.2	2.33	147	Retrospective	N/A	1985	Chandigarh & Ludhiana, India
St. George, Williams, et al. (1994)	12.9	149.4	0.57	415	Longitudal	1972 to 1973	1972 to 1991	New Zealand

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