

## Evolutionary Psychology

www.epjournal.net – 2012. 10(5): 830-841

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### Original Article

# Early Menarche as an Alternative Reproductive Tactic in Human Females: An Evolutionary Approach to Reproductive Health Issues

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**Abstract:** The age at which a female reaches sexual maturity is critical in determining her future reproductive health and success. Thus, a worldwide decline in menarcheal age (timing of first menstrual period) may have serious long-term consequences. Early menarcheal timing (first menstrual period before age 12) can have a negative effect on fecundity, as well as the quality and quantity of offspring, and may consequently influence population growth or decline. In this paper, we apply an evolutionary framework to modern human health, and assess both proximate and ultimate consequences of declining menarcheal age. Examination of human reproductive health within an evolutionary framework is innovative and essential, because it illuminates the ultimate consequences of a declining age of menarche and facilitates new ways of thinking about the long-term and intergenerational transmission of health and disease; thus, an evolutionary framework lends itself to innovative public health and policy programs. In this paper, we examine whether or not early menarche is an alternative reproductive tactic that modern human females employ in response to a stressful environment, and whether or not early menarche is ultimately beneficial.

**Keywords:** alternative reproductive tactic, development, fitness, health, maturation, menarche, puberty, reproduction

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### Introduction

The age at which human females reach sexual maturity, as evidenced by menarche (first menstrual period), is a critical determining factor of future reproductive success and overall health. There is currently a trend for girls to reach menarche significantly earlier than in previous generations across all racial and ethnic groups (Chodick et al., 2005; Demerath et al., 2004; Hulanicka and Waliszko, 1991; Hwang, Shin, Frongillo, Shin, and Jo, 2003; McDowell, Brody, and Hughes, 2007). This is potentially problematic since

accelerated menarche is correlated with a suite of negative health effects, such as: higher risk of breast cancer and ischaemic heart disease, stunted growth, earlier age in participation of risky behaviors, negative body image, higher likelihood of experiencing depression, suicide, inability to effectively deal with stress, early age at sexual debut and first childbirth, and lower offspring quality (Berezkei, Hofer, and Ivan, 2000; Brooks-Gunn, Petersen, and Eichhorn, 1985; Caspi and Moffitt, 1991; Chodick et al., 2005; Cooper et al., 1998; Dunger, Ahmed, and Ong, 2005; Ge, Conger, and Elder, 2001; Golub et al., 2008; Madrigal, 1991; Nichols et al., 2006; Pinyerd and Zipf, 2005; Tarullo and Gunnar, 2006). While many scholars have explored the proximate causes and consequences of menarcheal timing (e.g., Brooks-Gunn et al., 1985; Cooper et al., 1998; Ellis and Garber, 2000; Hoier, 2003; Matchock and Susman, 2006), we suggest a need to assess the ultimate (or evolutionary) causes and consequences of a declining age of menarche; this perspective will allow us to understand and predict the long-term effects that declining age of menarche has on the health of multiple generations, both within and among populations.

Examination of human reproductive health within an evolutionary framework is a potentially powerful (and novel) approach (see also Tybur et al., 2012) because it views reproductive developmental milestones (e.g., menarche) as part of an overall reproductive strategy designed to maximize reproductive success. For example, using an evolutionary framework, one can identify the function of menarcheal timing, conditions under which early (or late) maturation is beneficial, address how a shift in menarcheal age for some populations can contribute to demographic shifts in birth rates and overall health, and explain why sex differences exist in pubertal age despite males experiencing the same environmental stressors as females. Importantly, taking an evolutionary approach will determine whether declining age at menarche is an alternative reproductive strategy that confers a reproductive benefit under certain environmental conditions, and thus facilitate new ways of thinking about public health.

Here, we review the proximate correlates of early menarche, discuss whether variation in the timing of menarche across populations is adaptive in human females, and explain how to determine whether earlier menarcheal age maximizes individual female fitness. Finally, we will discuss the ways in which addressing reproductive health and development from this perspective may inform public policy as well as intervention and prevention programs.

### **Proximate Correlates of Early Menarche**

Humans are unique among mammals in that the timing of puberty onset varies over four to five years among individuals, even among individuals exposed to similar environments (Tanner, 1962). This variation has been attributed to both genes (Elks et al., 2010; Kaprio et al., 1995) and the environment; some studies suggest that genes account for approximately half of the variance in timing of menarche, while environment accounts for the other half (Susman and Dorn, 2009; Towne et al., 2005). However, some data now suggest that the environment plays a considerably larger role in determining the timing of menarche than do genes (Delemarre-van de Wal, 2005; Gluckman and Hanson, 2006a). This is not surprising: Since humans mature slowly, are long lived, have large brains, and

invest heavily in a small number of offspring, we have evolved internal systems that are highly sensitive to the physical and social environment (Belsky, Steinberg, and Draper, 1991; Ellis, 2004; Gluckman and Hanson, 2006a,b; Susman and Dorn, 2009). Furthermore, one hypothesis suggests that we have evolved to be especially sensitive to environmental cues during childhood in order to predict the availability and maximize the use of resources in the future (Belsky et al., 1991; Draper and Harpending, 1982).

Variation in pubertal timing may be an adaptive strategy to cope with unpredictable environments, and its existence suggests that variable timing of menarche is adaptive under certain conditions (Gluckman and Hanson, 2006a,b). For example, a stressful environment (e.g., low resource availability, social dysfunction) may signal low probability of survivorship past reproductive maturity. For humans, a stressful environment may be signaled by father absence and/or stepfather presence in the home, as well as older male sibling presence in the home (Belsky et al., 1991; Draper and Harpending, 1982; Ellis and Garber, 2000; Hoier 2003; Maestripieri, Roney, DeBias, Durante, and Spaepen, 2004; Matchock and Susman, 2006). In addition to psychosocial stress, exposure to endocrine-disrupting chemicals in the environment and low birth weight have been cited as proximate correlates of earlier menarcheal age (Behrman and Butler, 2006; Kuhl, Manning, and Brouwer, 2005; McLachlan, 1985). Nutritional status also affects timing of menarche; childhood obesity is a predictor of early menarche, just as low nutritional status can result in delayed menarche (Trevathan, 2010). Cues at the fetal stage can prime an individual for both childhood obesity and early menarche; data has shown that poor conditions in utero result in the fetus being primed to live in a stressful environment, and is more likely to develop obesity and early menarche (Gluckman and Hanson, 2006b). Consequently, stressed individuals typically mature early, and at a smaller body size, in order to reproduce before death (Thomaz, Beall, and Burke, 1997).

On the other hand, in environments lacking stress cues, individuals should delay maturity, achieve a larger body size, and maximize their reproductive lifespan. We can predict that in a stressful environment, individuals within a species who mature early will have higher reproductive success than individuals who mature later; in a stable environment, a longer maturation rate results in better health, longer reproductive life, and potentially more offspring (Gluckman and Hanson, 2006a,b).

The secular trend for declining age at menarche is well established: In the United States between the 1850s and 1950s, mean age at menarche declined from 17 to under 14 years old (Parent et al., 2003). In Israel, it declined from 13 to 11 years (Chodick et al., 2005), in Poland from 14 to 12 years (Hulanicka and Waliszko, 1991), and in South Korea girls are reaching menarche four years before their grandmothers did (Hwang, Shin, Frongillo, Shin, and Jo, 2003). Women in rural Gambia have experienced a decline in menarcheal age by 0.65 years of age per decade, with the average menarcheal age declining from 16 years in 1989 to 14.9 years in 2008 (Prentice, Fulford, Jarjou, Goldberg, and Prentice, 2010).

Gluckman and Hanson (2006a) suggest that the age at menarche in industrialized populations is now at the “evolutionarily determined range” (p.10); improvements in nutrition, medicine and hygiene over the past century lifted constraints on maturation rates in girls. This perspective suggests that early menarche is not an environmental or medical

issue, but a mismatch between biological maturation and psychosocial maturation. However, just because a trait confers reproductive fitness benefits does not mean it also increases the health of the individual. In addition, modern day humans face different environmental stressors (e.g., overexposure to endocrine-disrupting chemicals) than our ancestors did.

The proximate correlates of early menarche have been well established (e.g., stress, father absence, and low birth weight, as discussed above), but what has not been demonstrated is the ultimate, or evolutionary, cause of accelerated development. That is, researchers have not explored whether early menarche results in higher reproductive fitness under stressful conditions. Yet, as Dunbar (1982) noted, both ultimate and proximate factors need to be considered together when assessing variability in reproductive behavior. In the next section, we will discuss whether or not early menarche can be considered an alternative reproductive tactic that benefits human females and their offspring.

### **Alternative Reproductive Tactics**

Differential reproductive fitness (production of offspring) is the main outcome of natural selection, and diverse strategies have evolved in males and females across sexually reproducing species to maximize their reproductive potential. One strategy individuals may use to increase their relative reproductive output is employing alternative reproductive tactics. Broadly, alternative reproductive tactics (ARTs) are consistently varied reproductive behaviors and traits, within one sex in a population, that emerge when individuals within the same sex employ different reproductive behaviors or morphologies to better compete for reproductive resources (Gross, 1996; Oliveira, Canario, and Ros, 2008). ARTs allow an individual to maximize its fitness by allocating resources to different activities (i.e., growth, maintenance, or reproduction; Brockmann, 2001). ART expression is often extremely phenotypically plastic and sensitive to changes in the ecological and social environment (Emlen, 2008; Setchell, 2008). Alternative tactics can be irreversible (i.e., early vs. late maturation) or more flexible, allowing individuals to use different tactics over their lifespans (i.e., acquisition of territory).

Male reproductive fitness is limited by access to mates; thus, males within a species will alter their behavior or growth and development in an attempt to attract more mates and increase the likelihood of copulation (Alonzo, 2008). For example, some male orangutans (*Pongo pygmaeus*) develop cheek flanges early in life that function to show dominance and attract mates, while other males may not develop cheek flanges for decades after sexual maturity, thereby relegating them to a lower social rank and decreasing their chances of reproducing (Utami, Goossens, Bruford, de Ruiter, and van Hooff, 2002). ARTs can also take the form of alternative life histories; male Atlantic salmon (*Salmo salar*) may mature early in their life cycle or later and larger, after returning from a migration to the sea (Jones, 1959). Male waterbuck (*Kobus ellipsiprymnus*) use three different tactics to acquire mates: Bourgeois males defend territories, satellite males are tolerated on the periphery of a dominant male's territory, and bachelor males are not tolerated in a bourgeois' territory (Wirtz, 1982).

Although ARTs in females have been less studied than in males, there are

documented examples of female phenotypic and life history variations that function as alternative tactics. Some Old World monkeys employ pseudo-estrus, where a female monkey feigns estrous during pregnancy to copulate with a new alpha male in order to reduce the risk of infanticide via paternity confusion (Setchell, 2008). Additionally, Thomas' langurs (*Presbytis thomasi*) as well as mountain and western lowland gorillas (*Gorilla beringei* and *Gorilla gorilla*) employ a "harassment and avoidance" technique, where dominant females prevent low-ranking females from copulating via harassment, interruption during coitus, and aggression (Setchell, 2008).

Very little of this research on ARTs has been applied to humans (Cornwell et al., 2006) even though some have suggested the need to consider both alternative and conditional reproductive strategies in humans (Belsky, 2000, 2012). Therefore, a multi-disciplinary assessment of human evolution and modern health is needed (Belsky, 2010). Consideration of early menarche as an alternative reproductive tactic is one example of this multi-disciplinary approach. In order for early menarche to be considered an ART among human females, timing of puberty must fulfill three criteria: first, it should vary among individuals; second, it must confer a fitness benefit to the individual adopting it; third, it should result in competition with other females for access to reproductive resources. We know that menarcheal timing varies among individuals and has declined over time (Demerath et al., 2004; McDowell, Brody, and Hughes, 2007; Parent et al., 2003), and a downward shift in menarcheal age among women may indicate the increasing frequency of an alternative reproductive tactic that evolved to maximize fitness in response to environmental stressors. But does early menarche confer a fitness benefit? The conventional tactic (in this case, achieving menarche between the ages of about 12 and 14) should confer the optimal fitness benefit. Women who reach menarche at an average age would be expected to have more and healthier offspring than women who reach menarche earlier or later. However, early maturation should still confer some fitness benefit if it is indeed an ART.

### **Early Menarche and Reproductive Fitness**

Reproductive fitness is the average contribution of an individual to the gene pool of the next generation; basically, the success of an individual at reproducing offspring (Futuyma, 2009). The more offspring produced, and the higher the quality of those offspring, the higher reproductive fitness of the parent. But quantifying reproductive fitness, particularly offspring quantity and quality, is a hotly debated topic. Strassmann and Gillespie (2002) considered child mortality to be an indicator of reproductive fitness. Hill and Kaplan (1999) measure reproductive fitness as "...the intrinsic rate of increase...derived from directly summing reproductive output of each year lived" (p. 398). In their review, Strassmann and Gillespie (2002) suggested determining fitness by counting the number of offspring for women who have completed reproduction and whose youngest child is old enough to reproduce. They also suggested age-specific retrospective methods, which are more flexible and usually result in bigger sample sizes than the lifetime retrospective method. Using these methods, researchers can: (1) Count the number of offspring who have/had reached a certain age; (2) Count only the number of offspring alive

at the time of data collection. In general, considering both the number of offspring and the health of the mother and her offspring provides information regarding reproductive fitness.

#### *Number of Offspring*

Data show that girls who reach menarche early are more likely to achieve adult ovulatory cycles faster than girls who mature later, increasing the likelihood that early maturers will conceive (Kramer, 2008; Ellis, 2004). Thus, earlier age at menarche may afford the woman a longer reproductive lifespan by decreasing the age of first childbirth. Indeed, women are under selection for earlier age at first birth (Stearns, Byars, Govindaraju, and Ewbank, 2010; Byars, Ewbank, Govindaraju, and Stearns, 2010). Furthermore, Stearns et al. (2010) reported that women are under selection for later age at last birth in both non-industrialized and industrialized populations. Pumé foragers in Venezuela who reach first birth one standard deviation below the average age are four times as likely to lose their first born child, and have, on average, one more child than those who do not reach menarche early in order to obtain the same fitness level (Kramer, 2008).

#### *Quality of Offspring*

There may, however, be trade-offs to producing a large number of offspring; specifically, earlier age at menarche may reduce offspring quality. Offspring quality is directly related to the number of offspring that reach reproductive maturity, and may include characteristics like birth weight, adult body size, immune response, and growth trajectory. For example, data show that early maternal menarcheal age may contribute to low birth weight or preterm birth of the offspring, a higher risk of miscarriage, and increased risk of birth defects, all factors that would lower long-term reproductive fitness (Coall and Chisholm, 2003; Kramer, 2008; Liestøl, 1980). Early menarche is also correlated with higher preterm delivery (Li and Zhou, 1990), and higher offspring mortality (Kramer, 2008).

For early menarche to be considered an ART, it must also result in competition among women for access to reproductive resources. That is, one of the trade-offs for reaching puberty early (extending the reproductive lifespan) might be that a person is less desirable as a mate. One of the trade-offs for early maturation is smaller body size, which might be judged by a potential partner as showing reduced fertility. Males may not invest as many resources in a female who matures early versus one who matures later. The effect of this phenomenon may not be pronounced, as females are generally not limited by number of reproductive partners, and these hypotheses would be difficult to test in a human population.

Regardless of how reproductive fitness is quantified, we suggest that an early age at menarche may be an alternative reproductive tactic that functions in an unstable environment to maximize the reproductive fitness of an individual by extending her reproductive lifespan and thus affording her more time to procreate.

### **Current Reproductive Patterns and Demographic Shifts**

At the ultimate level, we can use evolutionary theory to understand current and

future reproductive patterns and demographic shifts and address questions such as, “What effect does early maturation have on reproductive fitness?” (Hochberg, Gawlik, and Walker, 2011) and “What long-term effect does a high frequency of girls who reach menarche early have on a population?” Since earlier age at menarche is a trend mostly evident in industrialized countries, it is possible that, worldwide, some populations may experience this shift and others may not. Within the U.S. population, ethnic disparities in menarcheal age (Parent et al., 2003) may contribute over the long-term to a demographic shift in quality and quantity of offspring. Additionally, those girls from disadvantaged backgrounds and recent migrants tend to reach menarche and/or puberty earlier (Parent et al., 2003). Since timing of menarche affects later adult health, and maternal menarcheal age influences both offspring quantity and quality, significant global demographic shifts may develop.

On a broader scale, a population-level shift toward earlier age at menarche may contribute to an increase in health problems (triggered by low birth weight, leading to obesity, early pubertal maturation, and associated long-term health problems, including breast cancer, polycystic ovary syndrome, depression, diabetes, etc.) that occur within families over generations, likely leading to increased medical costs and lower quality of life. In addition, a significant difference in menarcheal age across ethnic groups, as seen in the U.S., is possible in other areas of the world, and may contribute to an increase in health disparities within populations. Women who are members of groups that reach menarche earlier and who are already a minority, or disadvantaged in some way (i.e., Hispanics/Latinas in the U.S.) may experience further disadvantage if women’s health is in decline.

However, these potential demographic shifts assume that there is a change in the frequency of genotype (i.e., that there is selection on genes that cause accelerated development). An alternative hypothesis is that the genes that control development are flexible, and developmental rate is phenotypically plastic. This does not rule out the possibility of epigenetic effects becoming fixed in the population.

### **Application to Public Policy/Public Health**

Addressing reproductive health from both proximate and ultimate levels of causation contributes to a multi-level understanding of contemporary health issues and may help to explain the patterns we see in populations. At the proximate level, we can take immediate action by making small changes in our homes and communities that lead to immediate health benefits. We know that poor nutrition, obesity, family stress, abuse, and exposure to endocrine-disrupting chemicals contribute to early menarche. Since these environmental characteristics influence children’s growth and development, it is imperative that research informs legislators and policymakers on local, national, and international levels. On the local level, policymakers can legislate for increased consumption of organic, non-processed food at schools, as well as decrease or eliminate the use of toxic cleaners in schools and toxic fertilizers on school grounds. On a national level, policymakers can legislate to increase accessibility and affordability of organic and non-processed foods and work to eliminate food deserts in both rural and urban areas.

At the ultimate level, assessing public health from an evolutionary view is useful for informing policies with long-reaching implications, both temporally and geographically. For example, Stearns et al. (2010) noted that research on the health of contemporary humans from an evolutionary perspective may influence our understanding of the long-term effects of differential access to medical care, recent medical innovations, and the impact of public health messages and programs.

### **Future Directions**

We suggest that early menarche should be considered an alternative reproductive tactic employed by human females in order to maximize reproductive fitness in response to environmental variation. We also suggest that understanding how ARTs employed by humans affect long-term, intergenerational health and reproductive fitness is vital. Consideration of ARTs in human females may help to spur further debate regarding how to measure reproductive success in humans. Indeed, the role of menarcheal timing and other factors in reproductive fitness needs to be explored; for example, Hochberg et al. (2011) found that body mass, not age at menarche, was a better indicator of reproductive fitness.

In conclusion, viewing early menarche as an ART may lead to exciting new avenues of research by providing a novel way of thinking about human female reproductive health. New hypotheses, created within an evolutionary framework, can be tested using contemporary longitudinal and cross-sectional data. This information can be used to understand demographic transitions, as well as the effect that cultural attitudes and behavior have on fertility rates.

**Acknowledgements:** We thank Dr. Brenda J. Lohman, Allison Flittner, Angelica Reina, and Dr. Clint D. Kelly for thoughtful comments on this manuscript.

**Received 20 April 2012; Revision submitted 27 July 2012; Accepted 30 July 2012**

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