The Transition from Adolescence to Adult Life: Physiology of the ‘Transition’ Phase and Its Evolutionary Basis

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Abstract

The human life span is comprised of several life phases, each characterized by its own physiology. These phases (pre-natal, neonatal, infancy, childhood, juvenile, puberty, adolescence, prime and senescence) are important for the development of many biological and psychological processes. The ‘transition’ from adolescence to adult life in the human is a lengthy process in comparison with other species, and its evolutionary development has been long and complex. In this article, the characteristic features of this transition will be discussed, as well as the theory that the transition from adolescence to adult life should be considered as a life phase in its own right.

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Introduction

It is common to think of the human life span in terms of discrete life phases, each characterized by its own unique physiology [1, 2]. Such divisions may have important implications for understanding specific biological

and psychological processes, such as growth, pubertal development, socialization and intellectual maturation, and represent well-recognized milestones. Human life, accordingly, is customarily divided into the following phases: pre-natal (combined embryonic-fetal), neonatal, infancy, childhood, juvenile, puberty, adolescence, prime and senescence. While these phases clearly overlap, and although the divisions between any two may often be quite arbitrary, each phase is characterized by its own physiology, tempo and dynamics.

It is the thesis of this paper that the ‘transition’ from adolescence to adult life constitutes a similarly discrete life phase, characterized by its own inherent physiology. Consequently, it is inappropriate to consider this phase as a mere extension of adolescence or as an early aspect of mature adult life. Like other life phases, it represents the product of a lengthy and complex evolutionary process, and so is characterized by features unique to *Homo sapiens* as a species. When seen in this light, one may then ask the following questions concerning ‘transition’ as a life phase:

- 1 What are the physical characteristics of the ‘transition’ that distinguish it from adolescence and mature adulthood?
- 2 What is the physiological basis for the ‘transition’?
- 3 What is the evolutionary basis for the ‘transition’?
- 4 What are the implications for hormonal treatment?

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What Is the Difference between Puberty, Adolescence and 'Transition' as Life Phases?

Although the terms puberty, adolescence and 'transition' are often used interchangeably, in fact they refer to discrete life phases. Puberty defines a period of sexual maturation, correlating with the gonadarche and resulting from activation of the hypothalamic-pituitary-gonadal axis, as characterized by pulsatile secretion of gonadotropin-releasing hormone (GnRH). The most obvious features are the development of secondary sexual characteristics (some of which, especially in females, may actually be adrenal-, rather than purely gonadal-mediated) and the attainment of an acceleration of growth, culminating in the peak height velocity (PHV). There exists an interesting, although rather subtle, sexual dimorphism in the timing and character of these features that goes beyond the simple fact that girls enter puberty at an earlier age than boys. While both males and females attain PHV approximately 3 years after initiation of pulsatile GnRH secretion, girls, in general, are at an earlier stage of their pubertal development at the time of PHV (Tanner Stage 3 breast/Tanner Stage 3 pubic hair for girls vs Tanner Stage 4 genital/Tanner Stage 4 pubic hair for boys). Males are, generally, capable of procreation by the time PHV is attained, while females may frequently still be infertile at this milestone. Thus, while motile spermatozoa can be detected in urine or semen before male PHV, adult ovulatory patterns are not typically observed in females for several years post-menarche and well beyond PHV. This has important reproductive consequences for the species which are discussed below. Both boys and girls experience a pattern of growth deceleration before the pubertal growth spurt (-0.46 cm/year/year for boys and -0.48 cm/year/year for girls), so that the slowest period of growth in childhood is that immediately preceding the pubertal growth spurt [3]. When the minimal growth velocity is reached, acceleration then occurs, averaging $+1.66$ cm/year/year for boys and $+0.88$ cm/year/year for girls. Boys, thus, achieve a greater PHV, averaging 9.0 cm/year vs 7.1 cm/year for girls [2, 3].

Adolescence is a life phase that extends beyond the common physical features of puberty, lasting, on average, for 5–8 years after the onset of puberty (table 1). Just as with the pubertal and adolescent stages, overlap exists between the adolescent and 'transition' phases. Often, the physical changes of the 'transition' phase are subtle, to the point where the individual may not even be aware of experiencing them (in contrast to the tumultuous features emblematic of puberty and adolescence). Distinct charac-

Table 1. Characteristics of the adolescent life phase

Growth deceleration following the pubertal growth spurt
Complete eruption of permanent teeth
Completion of secondary sexual maturation, including menarche
Socio-sexual maturation within the individual's specific culture

Table 2. Characteristics of the 'transition' life phase

Epiphyseal fusion
Attainment of adult stature
Attainment of adult muscle mass, especially in males
Attainment of adult size of pelvic inlet (in females)
Fertility
Attainment of peak bone mass
Physiological homeostasis

teristics of 'transition' can, nevertheless, be ascertained, as described in table 2, and include attainment of adult stature with epiphyseal fusion, attainment of peak bone mass and full female fertility.

It is of note that while fertility occurs in males before the completion of puberty, this is frequently not the case in females, where attainment of normal fertility, as assessed by regular ovulatory cycles and ideal pelvic anatomy, may not occur for years after completion of puberty. Indeed, full reproductive capacity in females occurs post-puberty/adolescence and is rightly considered a 'transition' phase event. This is reflected not only in the irregular and often unpredictable fertility of adolescent females, but in the high incidence of intrauterine growth retardation and miscarriage observed in pregnancies occurring in teenage girls [4]. Similarly, the attainment of peak bone mass occurs post-puberty, typically between the ages of 18 and 25 years, and is a 'transition' event [5]. Thus, the 'transition' phase is best considered as a period when physiological homeostasis and full reproductive capacity are attained.

What Is the Evolutionary Basis for Adolescence and Transition?

Alexander [6] stated that '... juvenile life has two main functions: to reach the adult stage without dying and to become the best possible adult.' It is in this light that the evolutionary basis for puberty, adolescence and 'transi-

tion' should be viewed. The role of puberty is obvious: for a species to survive, individuals must achieve sexual maturation and reproductive capacity. Why, then, have post-pubertal adolescent and transitional phases?

Several aspects of human puberty, which distinguish it from that of other mammals, provide insight into this question (table 3). Puberty in *H. sapiens* is characteristically a late event, occurring after prolonged juvenile-childhood phases. In addition, puberty and adolescence are collectively lengthy periods of time, typically representing 5–8 years, compared with less than 3 years in most species of monkeys and apes. Finally, and most interestingly, *H. sapiens* represents the only species to have a significant pubertal growth spurt. While other mammalian species, especially social forms, exhibit gains in weight during puberty, only *H. sapiens* has a pubertal acceleration of height velocity, with PHV averaging 7–8 cm/year in females and more than 9 cm/year in males.

H. sapiens, as a species, is also characterized by relatively modest sexual dimorphism in stature. The ratio of adult female:male height is approximately 0.93, much higher than values seen in other mammalian species. Pre-pubertally, boys and girls are virtually identical in height, with boys being, on average, only 1.6 cm taller than girls at the initiation of female puberty. What limited sexual dimorphism in stature that is exhibited by *H. sapiens* is, in large part, due to differential growth that occurs during puberty-adolescence. Largo et al. [3], for example, determined that the 12.6 cm difference in adult height exhibited by Swiss men and women could be broken down to the following factors: (1) greater growth of males pre-pubertally (+1.6 cm for males); (2) delayed onset of puberty (+6.4 cm for males); (3) greater intensity of the pubertal growth spurt (+6.0 cm for males); (4) longer duration of growth after the pubertal growth spurt (+1.4 cm for females).

The pubertal growth spurt is only one of several perturbations in the growth trajectory of *H. sapiens*, which also includes a pattern of growth deceleration that starts from late gestation and continues after birth, a mid-growth spurt typically occurring at 6–7 years of age, and a pattern of growth deceleration immediately preceding the accelerated growth observed at puberty. The human growth curve is, in fact, extraordinarily complex and cannot be modelled with a single mathematical function. Leigh has stated that 'It might be best to think of growth spurts as modular and highly evolvable features of ontogeny. Natural selection (or sexual selection) can effectively 'put' spurts where (anatomically) and when they are needed to increase fitness. Perhaps we could propose that the

Table 3. Distinguishing features of the pubertal growth spurt of *H. sapiens*

Relatively late onset of human puberty, relative to childhood and juvenile phases (i.e. prolonged childhood-juvenile phases)
Relatively prolonged period of time between onset of puberty and adult homeostasis
Existence of a pubertal growth spurt

universal process is modularity and evolvability of growth spurts.' (cited in [3]).

This, therefore, raises the question of the evolutionary basis for the characteristic pubertal-adolescent-transition phases of *H. sapiens*. As is generally the case in such situations, one must beware of teleological reasoning, but, nevertheless, it is provocative to consider the following potential advantages of such a pattern of growth and maturation:

- 1 Delayed puberty results in a prolongation of the childhood-juvenile phases, thereby facilitating nurturing, socialization and the transmission of learning and culture from one generation to the next. This process is enhanced by the immature, juvenile appearance of a pre-pubertal child.
- 2 A smaller, less-mature child would have less demand for food than a rapidly growing, pubertal individual.
- 3 An immature-appearing child would be less threatening to adults in the society.
- 4 A prolonged childhood, characterized by a general pattern of growth deceleration, must be followed by a rapid growth phase in order for the individual to reach ideal adult stature. Increased size as an adult might be mandated by pressures such as defence against predation, ability to hunt and gather, ability to travel over relatively large distances including treeless areas, ability to maintain in utero and deliver a fetus/newborn with a relatively large brain and head, and, by sexual selection, a choice of mates.
- 5 Delayed fertility in females allows adolescent-transition females to attain ideal pelvic anatomy and size, complete growth and maximize skeletal mineralization, prior to the demands of pregnancy, lactation and child-rearing.

As Bogin has stated, 'we are developmentally delayed and growth-prolonged apes' [2]. The combination of pubertal, adolescent and 'transition' phases permits *H. sapiens* to sustain the growth, maturation and socialization necessary to its success as a species.

Indeed, these same factors provide a rationale for a growth pattern in *H. sapiens* that is characterized ultimately by epiphyseal fusion and cessation of growth during the 'transition' phase. The pressures that serve to provide a physiological limit to our growth include: (1) reproductive energy demands, especially in females, which preclude or curtail ongoing growth; (2) fetal demands; (3) lactation demands; and (4) the necessity of supporting our body weight on the ground (and the ability to support weight in trees, at least in the case of our ancestors).

Conclusions

It is the aim of this paper to place the commonly accepted patterns of human growth within a broad physiological and evolutionary framework. In this regard, it is essential to recognize that *H. sapiens* is unique in having a

complex, multi-modular growth pattern and a pubertal growth spurt. Presumably, these characteristics contribute to our reproductive success and survival as a species, and should be understood in this context.

The 'transition' phase is a life phase that has received little recognition, although it is clear that it represents a process whereby the individual secures reproductive success and physiological homeostasis, features that are essential to the survival of a species. It is important to understand that, from the perspective of evolution, ageing lies outside the domain of 'survival of the fittest' as the elderly provide little benefit to a species, other than whatever role they may have developed in transmission of knowledge or assistance in child-rearing. In this light, the 'role' of the 'transition' phase should not be thought of as promoting the survival of the aged. Indeed, it is neither an extension of adolescence, nor a preparation for senescence, but, rather, a legitimate life phase in its own right.

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