THE CONCEPT OF MATURITY FROM A MORPHOLOGICAL VIEWPOINT [1]

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The word "maturity," and its twin, "maturation," are two of the most loosely-used, poorly-defined, and overworked terms in the English language, ranging from biological "cell maturation," through cultural "mature behavior," to economic "value of a bond at maturity." The terms are, it seems, all things to all people.

In the present discussion we shall focus upon the use of maturity in growth studies, and shall limit ourselves in principle to somatic or morphological considerations. For the most part we shall consider quantity rather than quality, i.e., we shall assess categories of measurements and dimensionalities that may be utilized in setting up standards of morphological maturity.

Although Dr. Greulich will consider "Skeletal Aspects of Maturity," we cannot avoid a mention of this aspect in the present discussion, for the skeletal system is, after all, an integral and basic part of the morphology of the individual. Furthermore, so many estimates of morphological maturity are predicated upon skeletal advancement that we can scarcely divorce the one from the other. We shall discuss skeletal progress as a procedure, rather than as a concept.

The morphological role of the skeleton is best qualified by Todd (23) in the statement that "skeletal age is not a goal in itself, but is employed as an indicator of bodily maturity."[2] The so-called "Todd inspectional method," utilizing standard age-norms for hand X-rays, is too well known to need further elucidation. In his 1946 study of the development of strength Jones used skeletal X-rays as the basis of maturity ratings. Bayley (2) states that the analysis of skeletal development has provided us with "standards which allow for significant differentiation of skeletal maturity." To which she added that "skeletal age is . . . an indication of relative physical maturity, and complete closure of the epiphyses represents mature or adult physical status" (3).[3]

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[2] In 1931 Todd (22) used "skeletal maturity" and "skeletal differentiation" synonymously. McCloy (12) refers to "anatomical age or skeletal maturity"; he also refers to "physiological or maturational age."

[3] In a sense Cattell (5) follows this principle, though she uses progressive maturity to refer to the relative amount of bony tissue in the growing hand.

The use and interpretation of the skeletal X-ray as an estimate of maturity is not simple. Though a standard age-rating is suggested by Todd's *Atlas* (27), Pyle and her associates (13) consider the Todd inspectional technique principally as a method of estimating "the uniformity of maturation in regions of the skeleton." In 1942 Buehl and Pyle (4) stated that skeletal age, as a maturity category, must be "based on an aggregate of multiple maturity determinators." In 1943 Simmons and Greulich (20) concluded that "ideally a skeletal assessment would be a rating of simple maturity, uncomplicated by the growth factor ... but it is undoubtedly inevitable that, in the estimation of skeletal maturity, growth enters to some unknown extent."

The foregoing paragraphs bring to focus the problem of the relation of growth, per se, to maturity: can they be regarded as distinct? or are they complementary? or even synonymous? Todd (23) states as follows: "This business of growing up, growing older, growing old, is quite different from that of growing: it implies progressive maturity, not increasing dimensions." Simmons and Greulich (20) endorse this in principle when they conclude that "the maturational process differs from the growth process, and changes in skeletal development are, by observation, of a different nature from changes in size."

The use of the skeleton as an estimate of morphological maturity is, it seems, a basic technique. The skeleton is, of course, grossly correlated with growth in size; the skeleton gets bigger (i.e., the bones get longer, thicker, heavier), but this, alone, is but one phase of progress toward maturity. *Quantity*—mere size—is not enough. Something else is happening in the skeleton, something which may more appropriately be called a *quality*—progress toward an ultimate (adult) condition. In this sense, then, we use skeletal age, not as a correlate, but as a measuring unit, a standard, against which all morphological (including dimensional and observational)[4] maturity can be measured. The basic conceptual framework of skeletal maturity must be established in Dr. Greulich's paper.

Morphological maturity can be related to the growth process, per se, irrespective of any possible correlation with skeletal advancement. Todd (23) regarded skeletal age, height, and weight—in order—as the three best measures of "physical developmental growth" during childhood. Simmons and Greulich (20) refer to "certain maturational indicators, viz., chronological age at menarche, assessment of skeletal maturation, and standing height and body weight, together with their annual increments." In another context, however, they point out that "stature and weight are themselves variables at [sexual] maturity." McCloy (12) relates maturity levels to growth when he says that the "spurt in physical growth" is related to "maturation of the gonads."

[4] We are implying a dichotomy between measurement of size and proportions and the estimate of degree of change (as in secondary sex traits, for example).

The single, most often used estimate of morphological maturity is the adult value (of a dimension) or status (of a functional system). Scammon (9) employed this technique in his famed four patterns of growth (neural, lymphoid, general, genital). He used the attained value (dimension or weight) at 20 years of age as the adult, or 100 per cent value. Hence, this becomes the "mature" value, and chronological age-stages may be expressed in percentage terms toward maturity, i.e., the assumed "adult" or terminal value.

Wetzel (24, 25, 26) has built this concept of morphological maturity into his "Grid for Evaluating Physical Fitness." One of his three basic aims is "to measure and help guide individual progress from infancy to maturity" (25). There is a tacit beginning-to-end (infancy-to-adulthood) sequence.[5] Wetzel's rating of maturity is "the percentage level reached with respect to ultimate level, as determined by the upper level toward which the auxodrome in question is proceeding" (26). Here is an example of how it works: a boy, aged 12½ years, is at developmental level 150, on the 2 per cent auxodrome; since this auxodrome attains level 190 at 18 years (the 100 per cent or "adult" value), the boy at 12½ years is 150/190, or 78.9 per cent toward his maturity goal. Wetzel goes even farther when he recognizes that the attainment of maturity (the adult level) is relative, dependent upon the speed of the growing child: while a child on the 2 per cent auxodrome will achieve level 190 at 18 years, a child on the 98 per cent auxodrome need achieve only level 148 at 18 years. Yet at 190 and 148, respectively, each achieves his own mature rating.[6] Simmons and Greulich (20) endorse in principle the concept of the adult value as an index of maturity when they speculate upon "how far a child has progressed toward his own mature height." Bayley (2) uses the phrase "per cent of mature size" in setting up categories of predicting adult size ("complete growth"); again, she states that "among boys of the same chronological age the skeletally more mature boys are nearer their own mature size, the immature less so."[7]

Perhaps the most widely used concept of morphological maturity is that of puberty. There are, of course, physiological factors involved here, but we are referring only to concomitant bodily changes. Puberty is the time of sexual ripening and all that it implies. Richey (15) states that the onset of puberty is the standard of maturity, to which Abernethy (1) adds, "Age of onset of puberty is the most important index of general maturing,

[5] As early as 1908 Crampton (6) accepted the adult level as that of maturity when he defined adolescence as extending "from puberty to maturity."

[6] In the same vein, though expressed negatively rather than positively, Todd (23) stated that "retarded maturation is expressed in infantilism of bodily form, of face, and of behavior."

[7] West, quoted by Shuttleworth (18), employed the principle of the approach to the adult value when he assumed 12 measurements of the carpal X-ray in percentage of "mature development."

either physical or mental." Wetzel (24) builds his entrie concept of maturity around the advent of puberty.

The morphological definition of puberty centers around the complex of so-called secondary sex traits, i.e., the outward manifestations of dominance in maleness and femaleness. In this discussion we need not elaborate upon the cataloguing of the several traits;[8] it will suffice to note only certain basic data: onset of menarche, breast development, and general hirsute development. Richey (15) based his studies on the menarche in the female and the appearance of axillary hair in the male. Reynolds (14) states that in his study "sexual maturation was defined in terms of breast development."[9] Shuttleworth (17) states that "the process of sexual maturation in girls begins with the budding of the breasts, the appearance of pubic hair, and after some time culminates in the first menstruation or menarche." For boys a very careful and relative analysis (see Table I) is that of Greulich and his associates (8), who set up "five maturity groups which represent successive stages in the transition from the degree of physical immaturity which exists just before puberty to the degree of maturity which is usually associated with late adolescence." To the criteria of Table I must be added the skeletal evidence of Buehl and Pyle (4) who used three ossification centers (ulnar age, sesamoid age, iliac age) as a "measure of maturity" and as "a point in the maturation cycle of the male." It is important to note that the Greulich study, and to a lesser extent, that of Buehl and Pyle, recognize the relative nature of the attainment of maturity; the process is fairly orderly and regular; time of achievement may vary with growth pattern.

This quite logically—although not in an absolutely clear-cut manner—takes us from *maturity* as an end-product, an achieved state, to *maturation* as a process, as a series of way-stations along the path toward a final (adult) condition. There can be no reasonable doubt of the inevitability of morphological maturity; all things being normal, there must come a time when the process of growth reaches a terminus, a time when adult, or "mature," values are reached. There are still, however, certain residual problems relating to maturation, or the act of achieving maturity.

In 1937 Todd (23) wrote that "the maturation process ... depends ... upon general constitutional fitness, rather than upon the influence of a single controlling factor." Wetzel (24) feels that the maturation process is related to an inherent impulse to growth when he writes that "maturation is not directly related to age or to size, but rather to a more fundamental and critical property, viz., maximum deceleration of growth and

[8] Reference may be made to, among others, the studies of Crampton (6), Greulich (7), Greulich et al. (8), Kubitschek (11), Scheidt (16), and Shuttleworth (19).

[9] He found breast buds at 10.7 ± 1.1 years, pubic hair in girls at 11.2 ± 1.1 years. In girls McCloy (12) reported pubic hair at 13 years, 8 months, and for boys at 14 years.

development, and through this only indirectly to age." Maturation, is, in the sense of the foregoing, the *quality* of achieving maturity, which, in turn, may be rated as an ultimate *quantity*.

The problem of reliability of techniques and definition of process and status is a contradictory one. Stevenson (21) speaks of "the essential reliability of epiphyseal union as an indicator of [skeletal] age." Todd (23)

TABLE I

MATURITY GROUPS IN BOYS

(Greulich, et al., (8))

Group	*Penis, testes, scrotum*	*Pubic hair*	*Facial hair*	*Circumanal, perineal hair*	*Axillary hair*
1	Size as in early childhood	Pubic vellus as on ant. abd. wall	Only down hair	none	none
2	Penis longer, testes larger	Vellus developed into pigmented downy hair lateral to base of penis	As in group 1	none	none
3	Penis still longer, testes larger	Vellus continues development seen in group 2	Lightly pigmented hair at corner of lips and in front of ears in over ½ boys	Present in a few	Small hairs present in a few
4	Penis larger, especially in diameter, testes larger	Pubic hair like that of adult, though not so extensive	Slightly more developed than in group 3; slight hair on upper lip	Present in most	Present, though not as numerous as in adult
5	Are at max. size for the individual	Adult in quantity and type, and frequently in masc. pattern	Conspicuous hair on upper lip and sides of face and chin	Present, well developed	Present, well developed

states that "maturation is far less subject to fluctuation in progress than is growth." Simmons and Greulich (20), however, feel that none of the indicators of maturity "may be considered as an entirely satisfactory criterion." Specifically, they regard the menarche as "neither a dependable criterion of maturity, nor as necessarily the expression of any narrowly circumscribed stage of sexual maturation."

It is pretty clear up to this point that maturity, in a morphological sense, is an attained state, and that maturation is a phase, a time-linked aspect, of that state. It is equally clear that there are several indicators of maturity

and that there are, during growth, at least two great moments in the achievement of maturity—puberty and adulthood; the former is basically physiological (though it "triggers" certain morphological changes), the latter basically morphometric (size) and morphological (descriptive traits).

In a larger framework of biologic thought we would like to suggest that maturity is, in a sense, a climax of a biogenetic process; in this vein it may be considered as a never-ending series of climactic events in the life cycle of the organism. Therefore, the definition of maturity must shift with the stage or level of development unfolding that, in broadest aspect, we may call *organic growth*. Maturity, as a biological concept, thus becomes an aspect of the process of physical growth: it may be morphological, physiological, biochemical. It is rarely only one; it is generally all three, well-nigh inseparable.

If we accept the above premises, then, "maturity" need not cease with "growth," i.e., with the final cessation of bone growth that gives adult size, proportion, and configuration. We are suggesting that maturity applies with equal vigor and validity to the age-changes that supervene after adulthood is achieved (i.e., after about 21 years).[10]

The epiphyses of the long bones are said to be mature when there is synostosis at the epiphyseo-diaphyseal plane. This is at about 21 years; there are a few epiphyses left to unite, e.g., vertebral centra, scapular border, iliac crest, sternal end of clavicle, but practically speaking 20–21 years represents the attainment of skeletal maturity.

We see no valid reason why the same kind of thinking should not be extended to other morphological criteria of age in the human body, especially those best-known in the skeleton. The closure of the skull sutures is perhaps the best example of a maturation process that is often spoken of as simply an "age-change," rather than considered as part of the organic growth process. Yet the process of closure in sutures does not differ basically from that of epiphyseal union. There is no logical reason why we cannot speak of a patent suture as "immature," a closed suture as "mature." It is the ultimate destiny of a suture to synostose no less than it is of an epiphysis to unite with its diaphysis. Why, then, limit the concept of morphological maturity to only that period of life customarily spoken of as the "growth period?"[11] What of "growing old and growing older," to borrow from Todd's trichotomy?

Age-changes in the human body after the attainment of the adult state

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[10] In the first two decades of life the dental system comes to maturity: the teeth calcify and erupt. It is not unfair to say that the deciduous teeth are "mature" at about 36 months—they have fulfilled their destiny up to the point of complete growth in form, size, and function. Their subsequent exfoliation may therefore be said to be "postmaturational."

[11] To suture closure we might add the progressive definition of the pubic symphysis, and the architectural and textural changes of bones, especially on articular surfaces.

represent, for the most part, what we could call a "more mature" aspect of organic aging. It is true that very often the age-changes of later years are involutional and "senile," but then—and mayhap we belabor the point—so is a united epiphysis. The role of organic growth is ever from immature to mature; biologically speaking time has no value in the process. It is something that is morphogenetically bound to occur, and it *does* occur throughout the life cycle of each individual organism. It is time-linked only in the sense that progress to maturity is at different rates, and therefore occurs at different points in the chronological age-scale. A suture may be immature when an epiphysis is mature; bone texture may be immature when a suture is mature, and so on. The *process of maturation* is always going on in human tissues, leading to the ultimate *status of maturity* of each different structure.

The concept of morphological maturity is a difficult one to define within the bounds of sidereal time or organic structure. It is linked with biologic age and it is an expression of the growth potential of all tissues and systems. The process of aging we call *maturation;* the termination of that process—whenever it occurs in the life-cycle—we call *maturity.* These premises, we think, are basic to organic life.

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