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Mandibular Pubertal Growth Spurt Prediction. Part One: Method Based on the Hand-Wrist Radiographs

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SUMMARY

Many orthodontic treatment modalities will yield a better result in less time if properly correlated with the unique facial growth patterns of the patients. The pubertal growth spurt depends on gender and varies in relationship to the chronologic age. General skeletal maturity usually is used as an indicator to predict timing of mandibular growth velocity peak. Hand–wrist radiographic evaluation is one of the diagnostic tools currently available to determine whether the pubertal growth has started, is occurring or has finished. The overview of topic related literature and skeletal maturity assessment (SMA) system developed by L.Fishman are presented. The SMA system is based on eleven discrete adolescence skeletal maturational indicators of hand-wrist bones, covering the entire period of adolescent development. Maturational stage and level demonstrated close correlation with maxillary and mandibular growth velocity, amount of incremental growth and timing. Clinical indications for the use of hand-wrist radiographs to assess skeletal maturity are provided.

Key words: orthodontic treatment, hand–wrist radiographs, pubertal growth spurt

Understanding the development patterns of every growing patient is one of the prerequisites for successful orthodontic treatment. Many treatment modalities will yield a better result in less time if properly correlated with the facial growth patterns that are associated with the patient (1). Growth related appliances such as functional appliances, extraoral traction (headgear, facial mask), Herbst appliances must be used during periods of significant growth. Maxillofacial surgery contrarily, can be done only after the pubertal growth is over, because substantial growth afterwards may cause relapse. Early orthodontic treatment is often required during the mixed dentition if the skeletal maturation indicates growth velocity periods would be missed by waiting for more permanent teeth to erupt. On the other hand early orthodontic treatment is contraindicated if very little facial growth present.

Considerable variations exist in the timing of the development of different parts of craniofacial complex. Neurocranium growth completes approximately 80% of total growth by 6 to 8 years of age. The midface and the mandible have considerable amount of their total growth remaining between ages of 10 and 20 years. This makes possible to have a significant treatment impact on their final size during that time period. Orthodontists particularly are interested in the growth of mandible, because of its determinant role in the development of the anteroposterior relationship between the jaws. Mandibular growth is a target for dentofacial orthopedic therapy. Remarkable growth occurs of mandible during puberty. The pubertal growth spurts are dependent on gender and vary in their relationship to the chronologic age (2). These variations determine the speed and the duration of the growth processes. In girls, pubertal growth spurt usually starts between the ages 10 and 12 years, in boys between 12 and 14 years. Many studies have shown an association between peak velocity of facial growth and peak velocity of statural growth during puberty (3, 4, 5). It has also been demonstrated that the pattern of mandibular growth coincides with body height growth in adolescents (6). For the didactic purposes we can say that growth in height velocity curve approximately represents growth pattern of mandible (fig. 1). In fact mandibular growth, however, shows wide ranges of variability in amount, velocity and timing (7). Among these variables growth timing, which is the most critical for orthodontic treatment planning, can vary regarding the mean chronological age from 2 to 3 years on each side! It is obvious that chronological age is not sufficient for assessing the development stage of the mandible and the biological age or skeletal maturity has to be determined. General skeletal maturity usually is used as an indicator to predict timing of mandibular growth velocity peak. There are many methods attempting to measure general skeletal maturity. For this purpose body height (8), hand–wrist growth (9), sexual maturity (10) or cervical vertebrae bone age (11, 12, 13) are used. The first our article will attempt overview the relationship between the hand–wrist maturation stage, maturation level and growth changes in mandible. The second article will analyze correlations between cervical vertebrae maturation and prediction of mandible growth spurt.

Several human growth studies have shown that the timing of the pubertal growth velocity peak in statural height, as well as growth of mandible, is closely related to specific ossification events observed in the hand–wrist area (14, 15). Hand–wrist radiographic evaluation is one of the diagnostic tools currently used to determine whether the pubertal growth has started, is occurring or has finished (16). L.Fishman (17) developed a system of Skeletal Maturation Assessment (SMA). The system is based on the observation of ossification events localized in the area of the finger phalanges, carpal bone and radius. These processes were compared with mandibular pubertal growth spurt and close correlation between sequence of hand-wrist ossification and mandibular growth status was found. To understand the SMA it is necessary to remember the development of the hand and wrist. The initial skeletal component of a finger phalanx in embryo is cartilage. Bone replaces cartilage by a process termed endochondral bone ossification. Every phalanx has two centers of ossification. The primary ossification center appears in the central part of the phalanx (*dia-*

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physis) at about 2nd – 3rd month in utero. Later at about 2nd – 3rd year of life secondary ossification site, called *epiphysis,* develops (fig. 2). Finger phalanx epiphysis passes three bone formation stages (widening, capping, and fusion).

Epiphyseal widening. The widening of the finger phalanx epiphysis relative to its diaphysis is a progressive process. Epiphysis starts as a small center of ossification not very far from diaphysis. With the time epiphysis develops laterally to the width of the diaphysis (fig. 3).

Capping of epiphysis over their diaphysis. It occurs as a transition from initial widening to the fusion of epiphysis and diaphysis. At that stage rounded lateral margins of the epiphysis begin to flatten and point toward the diaphysis, with an acute angle on the side facing the diaphysis (fig. 4).

Fusion between the epiphysis and diaphysis follows capping. It starts in the centre and progresses laterally, until the two formerly separate bones become the one. The fusion consider completed when it is smooth continuity of the surface at the junction area and both ossification centers fuse forming one solid bony phalanx (fig. 5).

The SMA system identifies four stages of the hand–wrist bone ossification. These stages refer to specific development events, identified on hand–wrist x-rays, and are directly related with one or more levels of adolescent growth, such as the onset, peak or termination of maximum growth velocity. Six anatomical sites located on the thumb, third finger, fifth finger and radius (fig. 6) are used to evaluate skeletal maturity. L.Fishman described eleven adolescent skeletal maturation indicators (SMI's) found on these six sites and covering the entire period of adolescent development. Every SMA system stage takes some time span, so skeletal maturity indicators also describe the skeletal maturational progression during every of four stages. The SMI's are listed below in chronological order:

Stage No. 1 *Width of epiphysis as wide as diaphysis:*
1. Third finger proximal phalanx ($PP3_{e=d\ width}$)
2. Third finger middle phalanx ($MP3_{e=d\ width}$)
3. Fifth finger middle phalanx ($MP5_{e=d\ width}$)

Stage No. 2 *Ossification of:*
4. Adductor sesamoid of thumb (S)

Adductor sesamoid appears as a small center of ossification medial to the junction of the epiphysis and diaphysis of the proximal phalanx of the thumb (fig. 6). The first observation of the existence of this bone on the hand-wrist radiograph consider as its existence. This occurs after epiphyseal widening, but before capping in the other finger phalanges

Stage No. 3 *Capping of epiphysis*:
5. Third finger distal phalanx ($DP3_{cap}$)
6. Third finger middle phalanx ($MP3_{cap}$)
7. Fifth finger middle phalanx ($MP5_{cap}$)

Stage No. 4 *Fusion of epiphysis and diaphysis*
8. Third finger distal phalanx ($DP3_{fusion}$)
9. Third finger proximal phalanx ($PP3_{fusion}$)
10. Third finger middle phalanx ($MP3_{fusion}$)
11. Radius (R_{fusion})

When we know exact hand–wrist bone formation stage we can quite precisely identify the skeletal maturation stage and predict general somatic growth velocity. As we mentioned earlier the close correlation between the facial growth and general skeletal growth patterns has been found at most levels of maturation, particularly in relation to mandibular changes (18, 19). So, with SMA system we can quite precisely evaluate mandibular growth. Correlation of the ossification stages of hand–wrist bone and skeletal growth velocity for the period between 6 to18 years is shown in the Figure 7.

First SMI of hand–wrist bone maturation ($PP3_{e=d\ width}$) appears approximately 3 years before the peak of pubertal

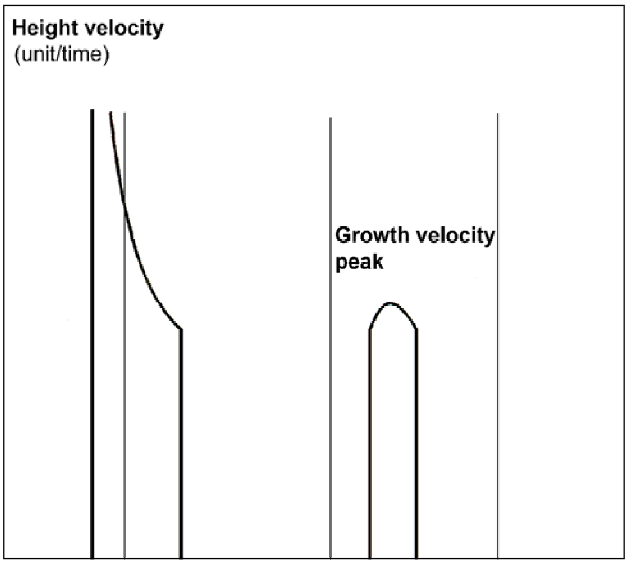

Figure 1. Skeletal growth velocity curve.

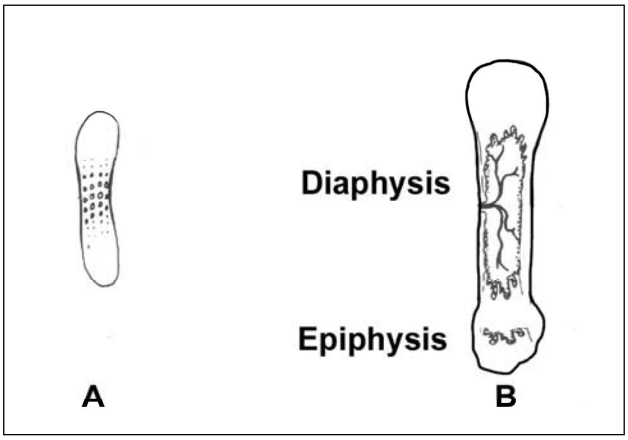

Figure 2. Schematic diagram of endochondral ossification.
A – original hyaline cartilage calcification starts in the center
B – bone formation continues in the diaphysis and secondary ossification site occur in the epiphysis

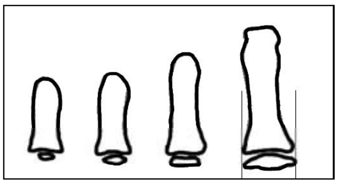

Figure 3. Radiographic identification of finger bone development progression. On the right - epiphysis equal in width to diaphysis.

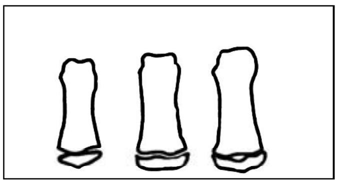

Figure 4. Capping of finger bone epiphysis.

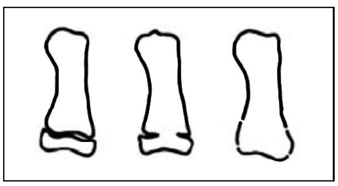

Figure 5. Fusion of finger bone diaphysis and epiphysis.

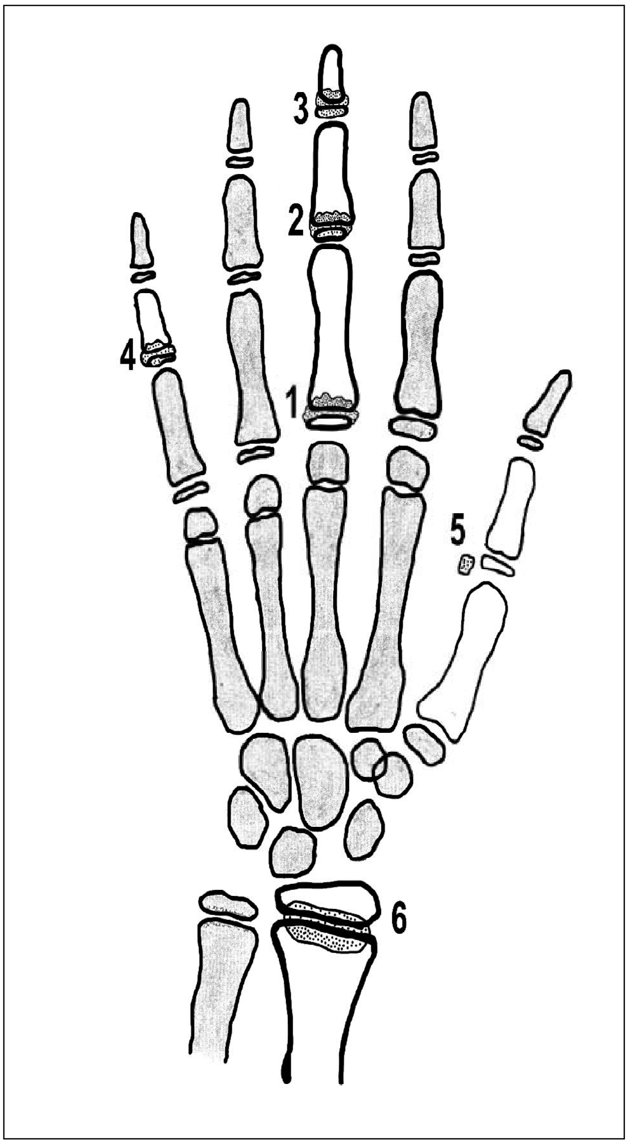

Figure 6. Anatomical location of skeletal maturity indicators:
1. Third finger proximal phalanx (PP3)
2. Third finger middle phalanx (MP3)
3. Third finger distal phalanx (DP3)
4. Fifth finger middle phalanx (PP5)
5. Adductor sesamoid of thumb (S)
6. Radius (R)

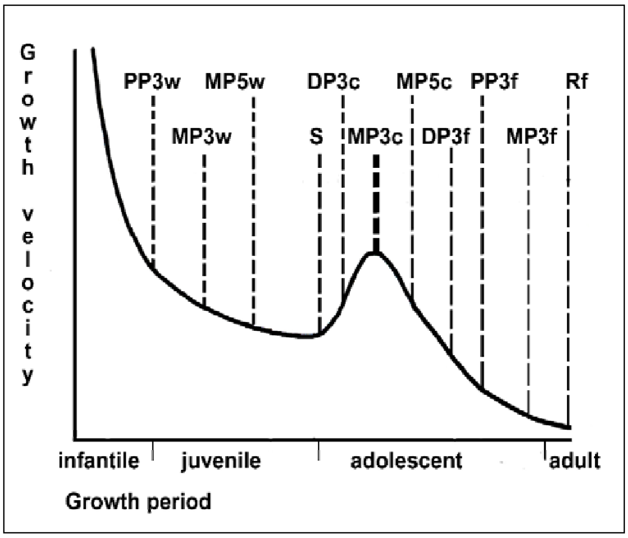

Figure 7. Relationship between hand–wrist bone ossification stages and skeletal growth velocity for the period from 6 to18 years.

growth spurt. Ossification of adductor sesamoid of thumb (S) occurs shortly before or at the beginning of the pubertal growth spurt. During the third stage of hand–wrist maturation diaphysis is covered by the cap-shaped epiphysis. The $MP3_{cap}$ stage of hand–wrist ossification marks the peak of the pubertal growth. Visible union of epiphysis and diaphysis at the distal phalanx of the middle finger ($DP3_{fusion}$) signify the end of pubertal growth. Complete union of epiphysis and diaphysis of the radius (R_{fusion}) indicate that the ossification of all the hand bone is completed and skeletal growth is finished. According to Bjork (19), the pubertal growth spurt ends even earlier, with complete fusion of the third distal phalanx ($DP3_{fusion}$).

A systematic observational scheme proposed also by L.Fishman can further facilitate SMI evaluation. Key stages are checked first, rather than looking for maturity indicators in numerical order, leading rapid identification of the applicable SMI. A useful first step is to determine whether or not the adductor sesamoid of the thumb can be seen. If not, then the applicable SMI will be one of those associated with early epiphyseal widening rather then capping. If the sesamoid is visible, then an SMI based on capping or fusion will be applicable. Hagg and Taranger (18) demonstrated that ossification of adductor sesamoid of the thumb was usually (86 percent of girls, 92 percent of boys) attained during the acceleration period of the pubertal growth spurt (from onset till growth velocity peak). Almost 100 percent of individuals had an ossified sesamoid at growth velocity peak. In 20 percent of girls and more than 30 percent of boys “S” SMI was attained in the same annual interval as the peak of the growth (20).

Dental, maturational and chronologic ages are not necessarily directly related, because every person matures on a very individual schedule (15). It has been demonstrated that during the adolescent growth spurt, the rates and magni-

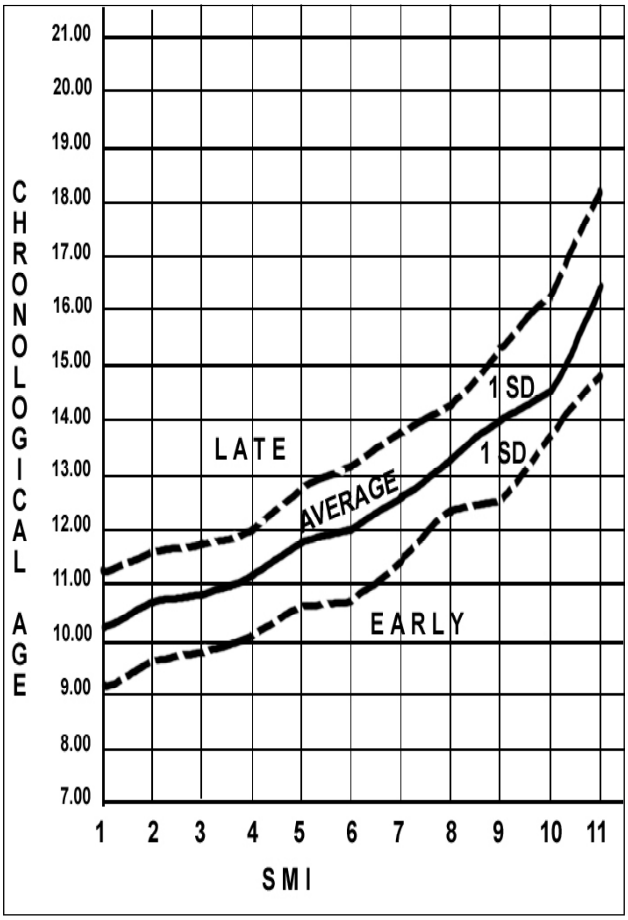

Figure 8. Levels of maturation, female (L.Fishman, 1987)

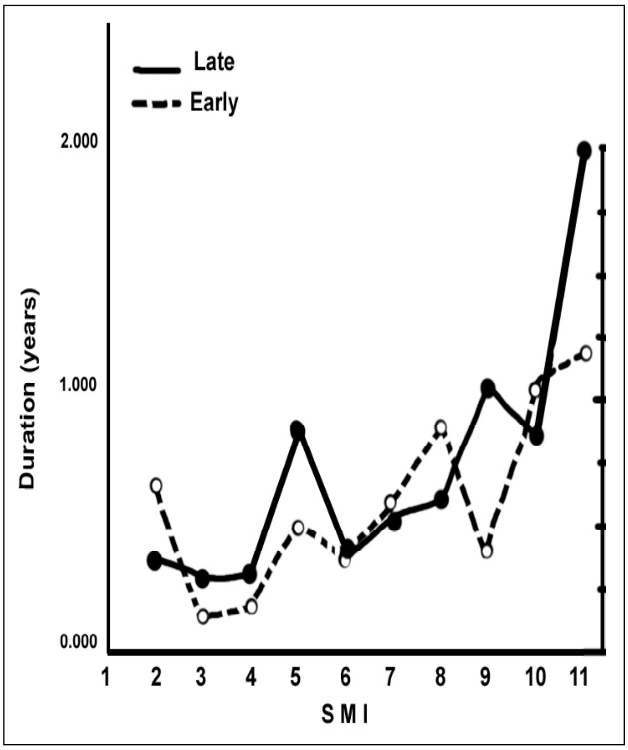

Figure 9. Levels of maturation, male (L.Fishman, 1987)

tudes of growth are different in those who mature early and those who mature late. Maturational age needs to be expressed in terms of *maturational stage* and *maturational level*. Maturational stages refer to specific development events, identified on hand-wrist x-rays, and are directly related to the progression of maturation during childhood and adolescence. The determination of maturational stages we have already discussed.

The maturational level is used to associate individual maturational stage with her or his chronological age. This indicates whether development is average, advanced, or delayed. Two children with the same maturational stage but different maturational levels will further demonstrate significant differences in the percentages of total maxillary and mandibular growth completed. The positive correlation between maturation levels and accelerations or decelerations in growth rates exists. L Fishman from 4.000 data records established chronological age mean values and standard deviations (SD) for each SMI's of both sexes (20). Individual chronological age values deviating by one SD or more from mean, were considered either late or early relative to their respective levels of maturation (fig. 8, fig. 9). This helps for the immediate assigning of an individual as being maturational early, average or late. The variations in maturational levels are directly related to differences in maxillary and mandibular growth velocity, amount of incremental growth and timing.

Time spans between the same maturational stages vary significantly among advanced, average and delayed maturers (fig. 10, fig. 11). Early maturers of both sexes exhibit almost identical SMI duration values for SMI's 1–5 and 7–11. The only significant difference in SMI duration for early group is between SMI 5 and 6. Girls usually reach the peak velocity of growth at SMI 5, and boys at SMI 6. For late maturation groups between the female and male less correlation is found. The female late group exhibits significantly longer time between SMI periods 4–5, 6–9, and 10–11. The male late maturation group exhibited longer time periods between SMI 2–4, 9–10 and 10–11. In general, advanced maturers progress through their maturational stages of development much faster than delayed maturers (20).

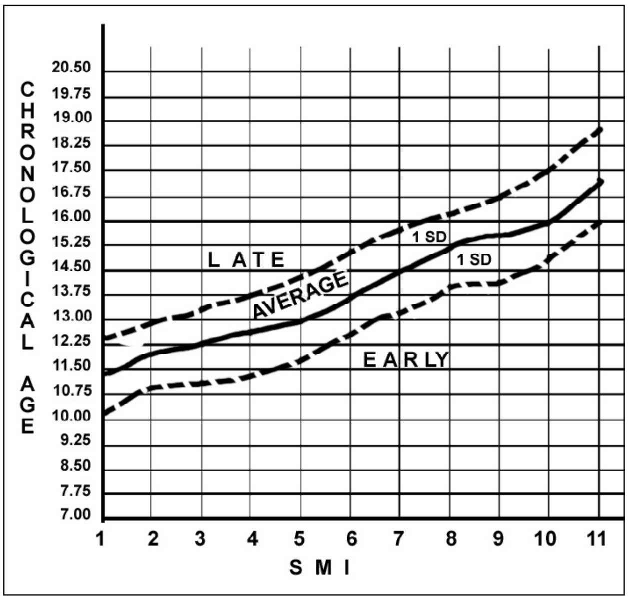

Figure 10. Duration of SMI's in early and late maturers, female (L.Fishman, 1987)

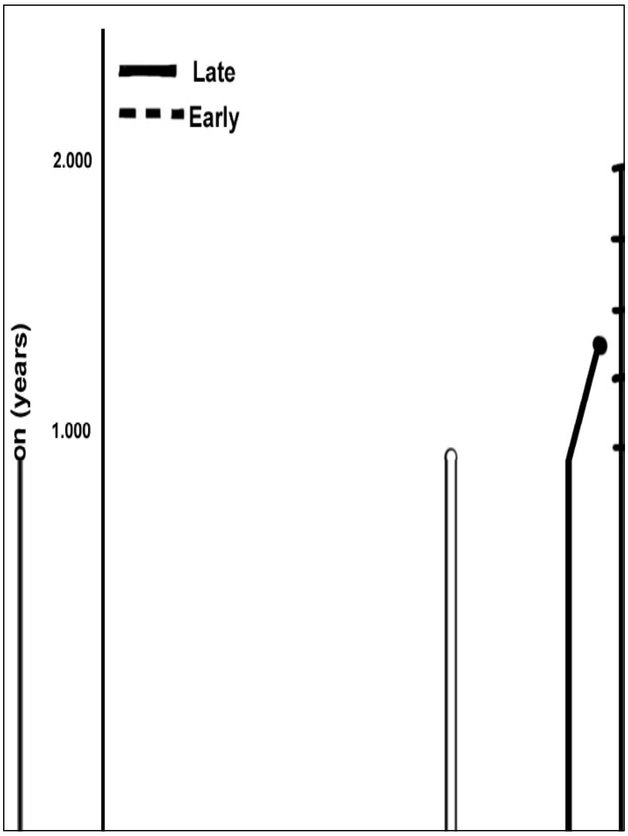

Figure 11. Duration of SMI's in early and late maturers, female (L.Fishman, 1987)

Mandibular growth rates of early and late maturers are significantly different during the late stages of pubertal growth. Late maturing individuals demonstrated larger growth increments as compared to average and early maturing individuals (21). During the later portion of adolescence when mandibular growth velocity is rapidly decelerating, delayed maturers exhibit a very significant amount of additional incremental growth as compared to average and particularly advanced maturers. Delayed maturers demonstrate 'catch-up' growth and take a longer time to accomplish it. This has significant implications relative to treatment timing, especially in Class III orthognatic surgery cases.

The application of SMA in a growth–related orthodontic treatment is a very useful tool for identifying most efficient starting points along the progressive path of adolescent growth. Evaluation of hand-wrist radiographs is indicated in the following cases: prior to rapid maxillary expansion, in skeletal Class II and Class III cases treatment, planning early orthognatic surgery for persons between 16 and 20 years, in patients with marked discrepancy between dental and chronologic age (22). The SMA system improves orthodontic treatment of most dentofacial problems regardless of appliance mechanics.

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