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Featured Review Article

Determination of timing of functional and interceptive orthodontic treatment: A critical approach to growth indicators

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ABSTRACT

Importance: Treatment timing of intervention for interceptive and functional treatments has been reported to be a critical issue in orthodontics when dealing with several types of malocclusions. Identification of the specific prepubertal, pubertal, and postpubertal growth phases, through the assessment of skeletal maturity, relies on the use of different growth indicators. These include the hand and wrist maturation (HWM), third finger middle phalanx maturation (MPM), cervical vertebral maturation (CVM), and dental maturation methods and others.

Observations: Reliability of the different growth indicators in the identification of the circumpubertal growth phases varies according to the indicator and growth phase, whereas data on true diagnostic capability of these methods is still limited to the MPM and CVM methods. Generally, optimal treatment timing for maxillary transverse deficiency, palatally displaced canines and skeletal Class III malocclusion should be early, (i.e., pre-pubertal), whereas optimal (functional) treatment timing for skeletal Class II malocclusion should be late (i.e., pubertal). Growth indicators are better used in combination or chosen according to the type of growth phase/malocclusion to be treated, with dental maturation having the least clinical applicability. Moreover, for radiographic indicators, ossification events should to be preferred over the use of single stages.

Conclusion: Although not all growth indicators proved to be fully reliable and in spite of the limitation of present evidence, the use of these growth indicators is recommended both in clinical practice and research.

1. Introduction

In orthodontics, determination of the timing of intervention for interceptive and functional treatments has been reported to be a critical issue to determine success or failure in the treatment of several types of malocclusions [1,2]. Optimal timing for orthodontic treatment, especially dentofacial orthopedic, relies on the identification of specific growth phases through the assessment of skeletal maturity. The relevant growth phases in orthodontically treated subjects are the circumpubertal ones, as the prepubertal, pubertal, and postpubertal growth phases [2–4], each of which is characterized by differential growth of the maxillary and mandibular basal bones [3,5,6]. Herein, the most investigated growth indicators are described, along with the optimal timing for interceptive and functional orthodontic treatment according to the type of malocclusion (including transverse maxillary deficiency, palatally displaced canines, skeletal Class II and Class III malocclusions). Finally, a critical approach to the use of the proposed indicators also has been reported.

2. Main growth indicators

2.1. Hand and wrist maturation method

One of the well-known hand and wrist maturation (HWM) methods is likely that proposed by Fishman [7], also referred to as skeletal maturation assessment (SMA). This method includes 11 stages (also defined SMI), in which stages 1 to 4 have been reported as prepubertal, those from 5 to 7 have been reported as pubertal, and the rest as postpubertal. Details of the method are reported

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elsewhere [7]. Another common variant of the method is that proposed by Hagg and Taranger [8]. These previous studies have reported a good correlation between the different stages of the methods and the pubertal growth phase as defined by mandibular growth peak [7] or standing height peak [8]. In this regard, the stage-based HWM methods have been reported as valid tools in assessing skeletal maturity, being independent of differences among populations and secular trends [9].

2.2. Third finger middle phalanx maturation method

Over the past 2 decades, the use of the sole third finger middle phalanx for a maturational method has been proposed [10,11]. This third finger middle phalanx maturation (MPM) method [10,12] would have the advantage of an easy interpretation of the stages, without double contours or superimposition by other structures. This method would be of easy execution, and may be performed in any clinical setting with minimal instrumentation and radiation exposure to the patient. In spite of the potential clinical advantages offered by the MPM method, current evidence is still sparse. Details of a five-stage MPM method have been recently reported by Perinetti et al. [12], who reported the MPM stage 2 to precede the mandibular growth peak, which is generally concomitant to the subsequent stage 3 with an overall diagnostic accuracy of 0.91. Although further investigations are needed, the MPM stages 2 and 3 have been considered associated with the onset and maximum mandibular growth peak, respectively.

2.3. Cervical vertebral maturation method

The cervical vertebrae modifications in growing subjects have gained increasing interest during the past few decades as a biological indicator of individual skeletal maturity. The cervical vertebral maturation (CVM) method was initially proposed by Lamparski [13] several decades ago. Subsequently, different versions of the method were proposed, including the one proposed by Baccetti et al. [2], which constitutes probably the most common CVM currently used both in research and clinical practice. This method comprises six stages (also defined CS), in which stages 1 and 2 have been reported as prepubertal, stages 3 and 4 have been reported as pubertal, and the rest as postpubertal. Details of the method are reported elsewhere [2].

Among the main advantages of the CVM method is that it does not require supplementary radiographic exposure, as for the HWM method, because lateral head film is usually available as a pretreatment record. However, contrasting evidence has been reported regarding the capability of the CVM method in the identification of the pubertal growth phase or mandibular growth peak. More in detail, few [14,15] or clinically relevant [2,16] correlations between mandibular growth peak and progression of the CVM stages have been reported. It has been suggested that reasons behind such apparent discrepancy may be related to the different CVM methods or designs used in previous investigations [1]. Even though mandibular growth peak has been reported to occur in coincidence with CVM stages 3 and 4 [2,17,18], further evidence from longitudinal studies is still necessary.

2.4. Dental maturation

A further proposed method for skeletal maturation assessment is that based on dental maturation, which can be easily assessed through the evaluation of tooth formation [19], and which can be carried out on panoramic or even intraoral radiographs that are routinely used for different purposes. The most common dental maturation method is that proposed by Demirjian et al. [19], which comprises eight stages from A to H according to the degree of tooth formation, and that can be applied to any tooth. Foreshortened or elongated projections of developing teeth will not affect the reliability of this assessment, as this method consists of distinct details based on shape criteria and proportion of root length, using relative values to the crown height. Details of the method are reported elsewhere [19].

Previous reports have shown a high degree of correlation between dental maturation and hand and wrist [20] or cervical vertebral [21] maturations, according to which dental maturation has been proposed as a reliable indicator for skeletal maturation assessment. However, diagnostic performance of these dental maturational stages remains sparse for mandibular canine, premolars, and second molars [22]. The only exception was seen for the mandibular second molar, in which complete formation of the distal apex (stage H) has been seen to occur generally in the postpubertal growth phase [22] or after the mandibular growth peak [23]. Interestingly, spontaneous eruption of maxillary canines has been reported to occur always before the closure of the apex of the mandibular second molar (up to stage G) [24], making this stage a potential indicator for the timing of interceptive treatment for palatally displaced canines [25,26].

2.5. Chronological age

It has been reported extensively that the average ages at the onset and peak of pubertal growth in stature are approximately 12 and 14 years in boys, and 10 and 12 years in girls [7,8,27–29]. However, high variability was seen among individual subjects and there is little diagnostic accuracy of the method [5]. Of note, onset of the pubertal growth phase is influenced by several factors, including genetics, ethnicity, nutrition, and socioeconomic status [30], responsible for a secular trend [31]. However, it has been reported that boys up to 9 years old and girls up to 8 years old are generally in the prepubertal growth phase [5]. Therefore, clinical applicability of chronological age as an indicator of the onset of the pubertal growth phase in the individual patient is very limited [2,8,12,18].

2.6. Standing height

Standing height has long been used as an indicator of the pubertal growth phase [32]. This procedure relies on serial recordings of standing height at regular intervals to build an individual curve of growth. Several investigations [3,32,33] reported a satisfactory degree of correlation between the standing height peak and mandibular growth peak, with an overall diagnostic accuracy in the identification of the mandibular growth peak between 0.61 and 0.95 [18]. According to this evidence, the recording of standing height may be useful in clinical practice to determine the onset of the pubertal growth phase, although true feasibility of the method limits its application in clinical practice.

2.7. Biochemical markers

The use of biomarkers has been proposed very recently as a new aid in assessing individual skeletal maturity with the advantage of avoiding radiation. The few data reported to date include biomarkers from the gingival crevicular fluid, such as alkaline phosphatase [34,35] or from the serum, such as insulinlike growth factor I [36–38]. These studies reported increased levels of the investigated biomarkers during the pubertal growth phase [34–38]. Of interest are the biomarkers from the gingival crevicular fluid, as its sampling involves a very simple, rapid, and noninvasive procedure

Table 1
Main types of malocclusion with suggested treatment modalities and timing of intervention with relative indicators

Malocclusion	Optimal timing of intervention	Treatment modality	Main reported effects	Main indicators	Stages
Constricted maxilla	Prepubertal growth phase	Rapid maxillary expansion [40,41]	Stable maxillary expansion due to a combination of skeletal and dentoalveolar effects	Chronologic age	Up to 8 y for girls and 9 y for boys
				Phase of dentition	Up to mixed dentition
				HWM	SMI1-SMI4 [7],*
				MPM	MPS1 [12],*
				CVM	CS1-CS2
Palatally displaced canines	Prepubertal growth phase	Rapid maxillary expansion with primary canine extraction [26]	Spontaneous eruption up to 80% of the cases	Phase of dentition	Up to late mixed dentition
				HWM	SMI1-SMI4 [7],*
				MPM	MPS1 [12],*
				CVM	CS1-CS2
				Mandibular 2nd molar maturation	Up to stage G [22],*
Skeletal Class II	Pubertal growth phase	Functional treatment either with removable [42] or fixed appliances [43]	A combination of skeletal and dentoalveolar effects	HWM	SMI5-SMI7
				MPM	MPS2-MPS3 [12],*
				CVM	CS3-CS4
				Standing height	Peak (a) [33],*
Skeletal Class III	Prepubertal growth phase	Facemask with or without maxillary expansion [44–46]	A combination of skeletal and dentoalveolar effects	Chronologic age	Up to 8 y for girls and 9 y for boys
				Phase of dentition	Up to mixed dentition
				HWM	SMI1-SMI3
				MPM	MPS1 [12],*
				CVM	CS1-CS2

CS, cervical vertebral stage; CVM, cervical vertebral maturation; HWM, hand and wrist maturation; MPM, third finger middle phalanx maturation; MPS, third finger middle phalanx stage; SMI, skeletal maturity index.
* Further indirect evidence.

that can be performed and repeated over time in a clinical setting, provided that optimal gingival conditions are present [39]. Currently, clinical applicability of such methods is still very restricted, mainly because of the lack of chairside kits and reference values.

3. Treatment timing according to the type of malocclusion

Different types of malocclusions require different timing of intervention. A brief list of the most common skeletal malocclusions (including palatally impacted canines), along with suggested treatment modalities and timing of intervention, is reported in Table 1 and detailed as follows.

3.1. Transverse maxillary deficiency

Transverse maxillary deficiency is a common type of malocclusion. This aspect is of relevance considering that unilateral or bilateral posterior crossbite may reach up to approximately 15% or more in schoolchildren [47]. To date very few long-term studies evaluated the skeletal effects of maxillary expansion treatment [40]. Of note, a controlled long-term study [41] included both prepubertal (showing CVM stages 1 to 3) and postpubertal (showing CVM stage 4 to 6) patients treated by rapid maxillary expansion. In particular, patients who were treated before the pubertal growth phase showed stable increments in maxillary skeletal width, maxillary intermolar width, and lateronasal width up to approximately 8 years later. On the contrary, patients treated after the pubertal growth phase showed only dentoalveolar effects after the same follow-up. Skeletal long-term effects after rapid maxillary expansion have also been reported recently, although this effect is still supported by low evidence [40]. Therefore, an early treatment at the prepubertal growth phase is recommended to treat transverse maxillary deficiency. Whenever possible, chronological age [5] and phase of dentition (up to mixed dentition) [48] may be used to assess timing for rapid maxillary expansion treatment, otherwise (in older patients) radiographic indicators, such as HWM/MPM/CVM methods, should be used.

3.2. Palatally displaced canines

Palatal canine displacement is a genetic disorder that often precedes tooth impaction, a dental anomaly the prevalence of which ranges from 0.2% to 2.3% of orthodontic populations [49]. A recent investigation has reported that rapid maxillary expansion treatment in conjunction with extraction of the deciduous canines is an effective interceptive treatment option that increases the rate of eruption up to 80% [26]. Timing for such intervention has been reported as prepubertal growth phase (according to the CVM method) and up to the late mixed dentition. However, prepubertal growth phase also may be assessed by the MPM stage 1 [12] or SMI1 to SMI4 [7]. Of interest, maxillary canines have spontaneous eruption in conjunction with mandibular second molar maturation stages E, F, and G, irrespective of growth phase, sex, and age [24]. By indirect evidence, and taking into account the duration of stages F and G [24], it might be indicated to begin interceptive treatment for palatially displaced canines no later than the passage between stages F and G in the maturation of the mandibular second molar.

3.3. Skeletal Class II malocclusion

Skeletal Class II malocclusion is one of the most prevalent dental and skeletal malocclusions in the sagittal plane, and it occurs in up to one-third of the population [50]. Mandibular skeletal retrusion is the most frequent diagnostic factor seen in such malocclusion [50], making functional treatment a valid option to enhance mandibular length. Previous meta-analyses [42,43] have reported how functional treatment for skeletal Class II malocclusion yields to favorable skeletal effects only when performed during the pubertal growth phase. Importantly, either removable or fixed appliance may produce skeletal effects, provided that proper skeletal maturation assessment has been performed (according to the HWM or CVM methods). By indirect evidence, the MPM method [12] also may be applied to identify the moment of mandibular growth peak, thus enhancing the skeletal effects of the functional treatment.

3.4. Skeletal Class III malocclusion

Skeletal Class III malocclusion has a prevalence between approximately 2% and approximately 17% in the general population [51]. Skeletal Class III malocclusion is established early in life and it is not a self-correcting disharmony [52], thus intervention in an early stage, such as deciduous dentition or prepubertal growth phase, has been recommended [44,45]. In particular, prepubertal treatment of Class III malocclusion by means of rapid palatal expansion and face-mask protraction yields favorable growth correction both in the maxilla and in the mandible [44]. Proper timing of intervention may therefore rely on chronological age [5] and phase of dentition [48] for very young patients, and on other radiographic indicators, such as HWM/MPM/CVM methods for older patients. Even though current evidence is in favor of early intervention, lack of high-quality studies with long follow-up regarding the efficiency of orthopedic correction of skeletal Class III malocclusion, also has been raised [46].

4. Critical approach to the clinical use of growth indicators

Most of the studies performed to date are based on correlation analyses between the stages/levels of a given growth indicator and circumpubertal growth phases [1]. However, correlations between parameters do not necessarily imply diagnostic accuracy [53]. To date, only limited longitudinal studies reported on the diagnostic accuracy of the CVM method and standing height [18] and MPM method [12] in the identification of the mandibular growth peak. Therefore, actual contribution of the growth indicators in the identification of the pubertal growth phase in individual patients still needs to be fully elucidated.

Specifically for the CVM method, a poor repeatability [54] has been reported, although this limitation may be avoided by proper training [55]. Finally, when assigning the CVM stage, it has been suggested that cases outside the reported norms may exist, and this may be responsible for doubtful interpretation or poor reproducibility [56]. In particular, these “exception cases” have been seen for the pubertal stage 4 [56], and their knowledge would be important to properly diagnose a given skeletal maturation phase.

Another relevant issue when dealing with any radiographic growth indicator relates to the use of single stages that may have variable and unpredictable duration, as it has been seen for the HWM [7], MPM [12], and CVM [14] methods, making the identification of the imminent growth spurt less reliable. In this regard, a distinction must be made between stages and ossification events [57]. The stages are specific periods in the development of a bone, whereas an ossification event represents the passage between two consecutive stages [57]. Therefore, the exact determination of the onset of the pubertal growth phase would require longitudinal recordings to monitor the ossification events. This aspect is of relevance considering that both the HWM method and the CVM method require films that are usually available as a pretreatment record, whereas optimal treatment timing may need to be delayed for an undermined term after the diagnosis (i.e., functional treatment for skeletal Class II malocclusion). Therefore, whenever possible, a serial monitoring relying on less invasive procedures, such as the MPM method [12] or standing height, should be preferred over growth prediction based on single staging.

Finally, considering the different capabilities of the growth indicators herein reported, the proper indicator may be chosen according to the type of growth phase that must be identified, and may thus differ as maturation occurs or the type of radiographic record available. Therefore, a combinational use of the different indicators may be indicated, even for the same patient who has to be followed over time, to enhance reliability of the diagnosis and to keep radiation exposure at minimal level.

5. Conclusions

Even though no indicator has provided a full diagnostic capability in the identification of the different growth phases, several clinical trials have shown how the use of indicators has led to a better response for a variety of malocclusions. Therefore, combinational use of the different indicators may provide an advance for the specialty, provided that operators are aware of the limits of each of the current indicators. In spite of the limitation of present evidence, the use of growth indicators is recommended both in clinical practice and research when dealing with malocclusions that require interceptive or functional treatments.

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