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REVIEW

Timing of early correction of mandibular hypoplasia in skeletal class II malocclusion: a review

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Abstract

Skeletal Class II malocclusion is a common malocclusion seen in clinics. It is characterized by maxillary protrusion and mandibular retrognathia and has a high incidence in adolescent mixed dentition and early permanent dentition. The early functional correction has achieved some clinical results in treating skeletal Class II malocclusion with mandibular hypoplasia. During treatment, the timing of correction is the key factor in determining the therapeutic effect, although it is difficult to understand. This review focuses on the timing of early correction of mandibular hypoplasia in combination with relevant assessment indicators and historical literature from four perspectives—the law of mandibular growth and development, the necessity of early treatment, the timing of early treatment, and the determination of the peak period of mandibular growth and development—to provide a theoretical reference for the timing of the treatment of clinical skeletal Class II malocclusion. This review shows that skeletal Class II mandibular growth has different characteristics in males and females. Bone growth assessment before treatment helps diagnose mandibular developmental morphology and the timing of early correction in adolescents with skeletal Class II malocclusion and hypoplasia of the mandible.

Keywords

Angle class II; Mandible; Early treatment; Timing of correction; Pubertal spurt

1. Introduction

Malocclusion can be categorized as skeletal Class I to III malocclusion [1, 2]. Although skeletal Class II malocclusion is a common malocclusion with a prevalence of between 5% and 29% [3], Class II malocclusion is an ongoing challenge for orthodontists [4]. Compared with patients with Class I and III malocclusions, patients with Class II malocclusion have a lower psychological, social, and physical quality of life [5, 6].

A Class II twin-block appliance can be used to stimulate and enhance mandibular growth in growing patients with skeletal Class II malocclusion with mandibular retrognathia [7].

The timing of treatment in dentofacial orthopedics involves a distinction between "early" and "late" treatment. In recent years, the appropriate timing of orthodontic intervention for skeletal Class II malocclusion has provoked considerable debate [8]. Routine early treatment, exposed by many experts, is intended to resolve or prevent skeletal discrepancies in all three spatial planes and to relieve common skeletal compression [9]. A recent review suggested the early reduction of anterior teeth protrusion protects against dental trauma [10]. However, some studies have found early intervention has not been superior to interventions in adolescents in terms of effectiveness [11, 12]. In orthodontic interventions for skeletal Class II malocclusions, it is important to target the early timing of orthodontic interventions so the surgeon can promptly identify and correct developing occlusal problems. However, many confusing and vague variables mislead this timing, for example, the developmental stage of the tooth and biological aspects of the skeletal maturation of the individual, which is easily overlooked or misinterpreted when assessing the optimal timing of treatment for mandibular dysplasia [13].

This review discusses the timing of mandibular hypoplasia in skeletal Class II malocclusion from the perspectives of mandibular development characteristics, the necessity of early correction, and the timing of early correction and analyzes the methods for determining early timing from multiple aspects. This review aims to provide a reference for determining the timing of the early correction of clinical skeletal Class II malocclusion and further promotes the development of treatment for skeletal Class II malocclusion.

2. Characteristics of mandibular growth and development

Embryologically, the mandible develops from the cartilage of the first pharyngeal arch (the mandibular process), known as Meckel's cartilage [14]. The growth direction of width, length, and height of the maxilla and mandible is completed in a certain order, with transverse growth completed first, followed by sagittal growth, and finally, vertical growth [15]. After birth, there are two main ways in which the mandible grows and develops. Except for endochondral osteogenesis at the condyle, the increase in mandibular volume is mainly formed by osteogenesis in the periosteum [16]. This subperiosteal bone surface matrix deposition is, in turn, associated with muscle action, condylar growth, and tooth eruption and thus determines mandibular growth [17].

2.1 Sagittal development

During the process of bone growth and development, one part is continuously remodeled into another part; the whole bone is continuously enlarged, although the overall external shape of the bone remains unchanged, and the shape and size of all parts undergo extensive replacement during migration [18]. With the growth and development of the nasopharynx and maxillary complex, the mandibular ramus gradually becomes upright, more bone deposition occurs in the lower posterior margin than in the upper, and more bone resorption occurs in the anterior and lower margin than in the upper, resulting in the “rotational” growth of the mandibular ramus. The growth direction of the condyle also becomes more upright, so the mandibular ramus gradually becomes smaller (Fig. 1). The sagittal development of the mandible is mainly characterized by growth in the anteroposterior direction of the mandible [19]. The growth of mandibular length depends on the absorption of old bone from the anterior border of the mandibular ramus and the proliferation of new bone from the posterior border [20]. During mandibular development, fibrocartilage stops proliferating at the raphe, and endochondral ossification occurs, creating a permanent osseous symphysis. Thereafter, the mandibular ramus is moved posteriorly, and the mandible is lengthened by bone formation at the posterior margin of the ramus and bone apposition at the anterior margin. At the same time, bone formation is faster than bone apposition, so the width of the ascending ramus increases. The anterior border of the ramus begins to form new material for remodelling the mandibular body; this process of gradual movement with skeletal enlargement is known as regional resetting of the mandibular body. The entire mandibular ramus is repositioned posteriorly, and the bone site growing posteriorly migrates to a position previously occupied by the ramus, causing the part of the ramus to become a new part of the mandibular body, resulting in the sagittal lengthening of the mandibular body [21]. The mandible is displaced anteriorly as a whole, and the degree of movement is the same as the degree of posterior displacement of the ascending ramus, which is associated with the enlargement of the mandible itself, and the bone is continuously remodelled while displaced, maintaining consistency with the degree of displacement.

2.2 Vertical development

Newborns are born with a short ramus and a blunt mandibular angle. The mandibular angle becomes progressively sharper as the newborn begins to chew. However, when the tooth is completely lost, the alveolar process is absorbed, and the mandibular angle becomes blunted. This suggests that the morphology of the mandibular angle is closely related to muscle function [22]. Björk [23] found that when vertical condylar

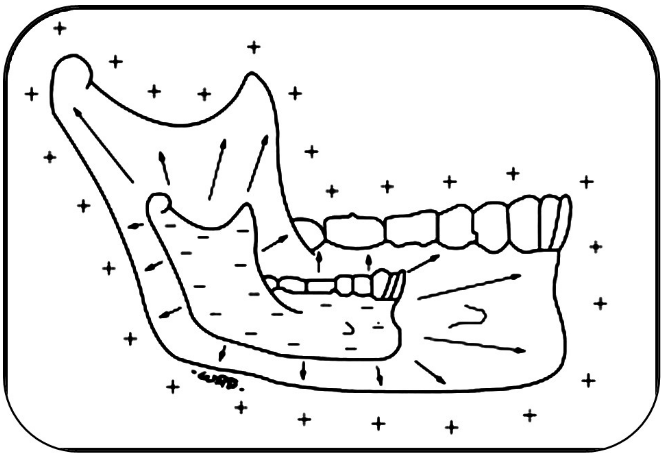


FIGURE 1. The external morphological characteristics of the mandible are changed with growth and reconstruction.

growth was evident, the mandibular angle tended to sharpen, and the lower molars tended to erupt more medially; when anterior condylar growth was more significant, the mandibular angle increased, and the lower molars tended to erupt more distally.

The mandibular body is mainly elongated posteriorly, and the mandibular ascending portion is gradually remodelled into the posterior part of the mandibular dental arch. With the upward and backward remodelling of the mandibular ascending branch, the vertical height of the ascending branch increases, favoring its horizontal expansion. At the same time, the occlusion of the maxillary and mandibular teeth is opened because the mandibular arch is displaced downward and anteriorly; upward posterior growth of the condyle causes the mandible to undergo corresponding downward and anterior displacement, so the mandibular ramus shows enlargement both vertically and horizontally [24], allowing the mandibular arch to further descend and open the occlusion. To maintain facial balance, the total vertical growth of the mandible matches the total vertical growth of the nasomaxillary complex and the amount of upward eruption, and a cumulative change of the mandibular alveolar ridge [25, 26].

2.3 Mandibular rotational direction

From a growth perspective, the mandible can be considered a more or less unconstrained bone because it can change its inclination in multiple directions; the key factor is the position of the center of rotation [27]. Gesch *et al.* [28] performed a longitudinal study of 40 adolescent patients with skeletal Class II malocclusion and found that the mandible rotated anteriorly during the growth phase. Björk *et al.* [29] suggested that mandibular stromal rotation is the rotation of the mandible around the condyle. However, the mandibular growth direction is not always linear and is usually slightly curved anteriorly and sometimes posteriorly; therefore, the mandibular growth pattern is usually characterized by the upward- and forward-curved growth of the condyle. At the same time, the curvature of the mandibular neural tube also reflects the shape of the early mandible. When uncoordinated anterior and posterior mandibular height growth occurs, mandibular growth rotates. This is mainly manifested as anterior mandibular rotation, when the posterior height growth of the ascending branch is greater than the anterior height growth, and as posterior mandibular rotation when the anterior height growth of the ascending branch is greater than the posterior height growth [30]. The presence of these imbalances in the growth of the mandible causes the mandible to rotate.

The rotation of the mandible has a certain influence on the mandibular plane angle and plays a key role in the control of the vertical direction during orthodontic treatment. In general, the mandible rotates about 15° anteriorly and internally and 11° to 12° externally, reducing the mandibular plane angle by only 3° to 4° [31]. The intersection angle of the upper and lower central incisor axes affects the rotation of the mandible. When the eruption direction of the mandibular incisors is upward and forward, the normal internal rotation of the mandible brings the anterior part of the mandible upward, and this rotation changes the eruption of the lower incisors and moves the teeth backward. When there is internal rotation, the upright incisors, and lower molars move proximally and centrally, which shortens the length of the lower arch. As the mandibular anterior rotation is larger than the maxilla, the lower arch is more prone to arch shortening than the upper arch, crowding the dentition [32]. It can be said that the rotation of the mandible is often a factor responsible for crowding the anterior arch of the mandibular dentition.

3. Necessity of early correction of mandibular hypoplasia

Mandibular hypoplasia severely impacts patients' quality of life [33]. The maxilla and mandible are prone to exhibiting complex morphological differences due to the complex mechanism of bony incongruity between the mechanisms of the jaw and dental arches in three dimensions. The most common problem of bony deformity in orthodontic clinics is Class II malocclusion with mandibular retrognathia, and intraoral examination often shows a narrow upper dental arch, a deep overbite, and a molar distal relationship [34]. Sari *et al.* [35] found that one-third of adults had a poor profile, chin, and jaw development and sought orthodontic treatment due to a compromised appearance. Pancherz *et al.* [36] compared the morphology of the lateral cephalograms of 347 cases of Class II, Division 1 malocclusion and 156 cases of Class II, Division 2 malocclusion and found a high incidence of mandibular hypoplastic retrognathia. In China, the incidence of Angle's Class II malocclusion is 20.05% in adolescent malocclusion, and the incidence of Angle's Class II, Division 1 is 15% to 20%. Those with mandibular retrognathia as a single factor account for 49% of patients treated for Angle's Class II, Division 1. The proportion of mandibular retrognathia in adolescents increases year by year with age [37]. Some studies have reported that mandibular retrognathia can lead to sleep apnea syndrome, which can cause hypertension, myocardial infarction, and other diseases [38, 39].

It can be seen that malocclusion caused by mandibular dysplasia seriously affects patients' quality of life and psychological self-esteem. For mandibular hypoplasia without growth potential, camouflage treatment with tooth extraction is often required to mask developmental incoordination in the bony sagittal direction. However, camouflage treatment with tooth extraction has limited efficacy in improving the profile and chin [40]. If the degree of bony deformity is severe and the mandible underdeveloped, combined correction with orthognathic surgery is also required [41]. However, the treatment time is long, the patient suffers major trauma, and the long-term stability effects cannot be guaranteed.

The use of functional appliances (FAs) in patients with skeletal mandibular hypoplasia has been recognized by many scholars to improve both facial aesthetics and oral function. Perinetti *et al.* [42] conducted a systematic review and meta-analysis of the treatment effects of FAs and concluded that such appliances can improve the relationship between the maxilla and mandible in adolescents. However, there are different views on whether FAs promote the growth of the mandible, increase the absolute mandibular length, or induce early mandibular growth and development [43]. Animal studies by Proff *et al.* [44] have shown that forward mandibular displacement enhances condylar growth, resulting in significant changes in the morphology of the mandible. Such induced condylar growth has been shown to be characterized by a thickness of proliferative layers of condylar cartilage on the posterior aspect of the condyle, thus yielding an increase in total mandibular length. Hong *et al.* [45] found in animal experiments that FAs accelerated the differentiation of condylar mesenchymal cells and promoted cortical osteogenesis, thereby promoting condylar growth. Faltin *et al.* [46] found that dual-stage treatment of skeletal Class II malocclusion with functional correction significantly promoted the growth of the mandibular ramus. As adolescents are at the peak of growth and development, inducing and stimulating condylar growth to induce skeletal reconstruction can provide them with an improved lateral appearance or a better foundation for later orthodontic treatment.

4. Timing of early correction

The effect of orthodontic treatment in adolescent patients with skeletal Class II malocclusion is better. The mandibular growth trend (direction) in patients with skeletal Class II versus skeletal Class I does not differ throughout puberty, but the growth is not static [47]. Bishara *et al.* [48] found that the growth trend of skeletal Class II mandibles was not significantly different from that of normal mandibles in each dentition period. However, the total growth volume of skeletal Class II mandibles from the early permanent dentition period was significantly lower than that of a normal group. Buschang *et al.* [49] showed that the maxilla grew linearly throughout the age range and remained stable in relation to the skull base, whereas mandibular measurements showed a markedly increased growth rate; patients with skeletal Class II malocclusion had a significantly slower mandibular growth rate than patients with skeletal Class I malocclusion from the age of 11 to adolescence. In 1997, Ngan *et al.* [50] found that differences in mandibular growth in adolescent females with skeletal Class II malocclusion emerged at seven years of age and persisted into adolescence; they manifested mostly as mandibular retrognathia or a combination of horizontal and vertical mandibular deformities, and these skeletal differences persisted in the absence of orthodontic intervention during childhood.

Franchi *et al*. [51] investigated 51 subjects with skeletal Class II malocclusion (females and males) to assess the efficacy of FAs and fixed appliances in patients. They found that the factors affecting efficacy were the type of FA, patient compliance, and the timing of early intervention. Reliable measures detected mandibular growth at different skeletal maturity, and the results showed the mandibular angle (Co-Go-Me) measured <125.5° at the (CS3 stage) for each cervical spine fragment in patients with Angle's Class II, with mandibular bone improvement. The patients responded well to correction methods, including FAs. It is suggested patients with boney Class II mandibles treated at the peak of cervical skeletal maturation (CS3 stage) have a better outcome, while patients beyond the CS3 stage respond poorly to functional orthopedic treatment.

In addition, changes in the direction of condylar development are one of the important skeletal effects of FAs in adolescence [13]. Perinetti *et al*. [42] investigated the therapeutic effect of removable FAs on prepubertal and pubertal patients with Class II malocclusion through a systematic review and meta-analysis of controlled studies. Their results showed that orthodontic treatment at the pubertal growth stage could effectively correct clinically relevant skeletal effects of Class II malocclusion. Recent studies have also shown that patients in adolescence are not adversely affected by interrupted treatment or delays in orthodontic treatment with twin-block appliances [52].

It can be seen that adolescence is related to the peak period of mandibular growth and development and is also the optimum period for correcting skeletal Class II malocclusion with mandibular hypoplasia. Understanding this timing will greatly improve the effect and success rate of correction. However, significant individual differences exist in the onset time, duration, and degree of pubertal spurt. Therefore, functional correction using the growth potential of patients is a key factor in the success or failure of early correction.

5. Determining peak mandibular growth and development

The mandible grows at a relatively stable rate before puberty, and the fastest period of mandibular development is during youth, which is manifested in a series of changes in facial skeletal indicators. These measurements affect the relationship between the dental and facial parts. Orthodontists need to know craniomaxillofacial growth and development to effectively optimize the timing of the early orthodontic treatment of patients with skeletal Class II malocclusion and underdeveloped mandibles [53]. Bishara *et al*. [48] showed that mandibular growth volume and velocity did not alter significantly in the prepubertal development period. However, mandibular length increased significantly after early adolescence to complete the eruption of permanent teeth, but the growth of the Class I mandible was still greater than that of the Class II mandible.

Different individuals of the same age have individual differences in jaw growth and development stages, necessitating a prediction of their individual growth and development status. The physiological characteristics of individual growth and development are assessed mainly according to bone age, sex, dental age, secondary sex characteristics development, and other related factors [54].

5.1 Correlation between mandibular spurt stage and bone age

Bone age can be assessed to determine the bone growth potential in adolescents when the development of the maxillary and mandibular ilium is inconsistent. Radiographic calcification and fusion of the epiphyseal and diaphyseal cartilage carpal bones (commonly, the left hand) and a modified cervical staging method are generally used in orthodontic clinics to determine skeletal maturity [55].

Dentofacial development is consistent with general development. The pubertal spurt is often divided into three stages: acceleration, peak, and deceleration [56]. A study by Perinetti *et al*. [57] investigated 451 subjects, including 231 females and 220 males between 7 and 17 years of age. They examined radiographic images of the middle phalanx of the third finger and lateral cranial views and showed consistency between the two methods for diagnosing bone age: the third middle phalanx maturation (MPM) method and the cervical vertebral maturation (CVM) method. To further confirm the reliability of the MPM method in identifying peak mandibular growth, Perinetti *et al*. [58] analyzed 15-year follow-up data from 35 patients in 2017 to revalidate the correlation between middle finger maturity and peak mandibular growth, implying a positive role of middle finger maturity in the timing of treatment. The metaphyseal ossification stage (MPS) of the middle phalanx of the finger consists of five periods (Fig. 2):

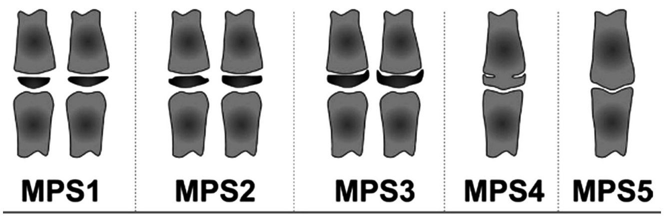


FIGURE 2. Modified schematic of the third phalanx maturation. MPS: middle phalanx stage.

(1) MPS1 stage: When the epiphysis is narrow with the metaphysis, or the epiphysis and metaphysis show a tapered and rounded lateral margin, it suggests that the epiphysis is not fused with the metaphysis.

(2) MPS2 stage: When the epiphysis is as wide as the metaphysis, the thickness increases on both sides, and a clear demarcation line is shown at a right angle with or without lateral steps in the upper contour. Where there is an asymmetry between the sides, the more mature side is used to assign stages.

(3) MPS3 stage: The lateral metaphysis shows an initial cap when the epiphysis is as wide as or wider than the metaphysis. If the sides are asymmetric, the more mature side is used to assign stages, but the epiphysis is not fused with the metaphysis.

(4) MPS4 stage: When the epiphysis fuses with the metaphysis, the covering remains detectable; although the contours of the former remain clear, the two sides of the epiphysis form obtuse angles with the distal boundary.

(5) MPS5 stage: This is the complete fusion of the epiphysis with the metaphysis.

The growth trend of the mandible corresponding to the middle finger of the third finger in males at each actual age (including 15 years) is shown in Fig. 3. In this case, each MPM stage lasted approximately one year from stage 2 to stage 5. In particular, peak mandibular growth occurred mostly at 12 to 13 years of age, MPS2 at 12.2 years, and MPS3 at 13.3 years of age. In females, peak mandibular growth occurred mostly at 10 to 11 years of age, MPS2 at 10.5 years of age, and MPS3 at 11.3 years of age. Perinetti *et al*. [58] also found that MPS2 and MPS3 may be related to the onset and maximum peak of mandibular growth, respectively. Mandibular growth generally peaks later in males than in females. In 2014, the results of a study by Perinetti *et al*. [57] on 350 subjects showed that females usually enter phase MPS2–6 one year earlier than males. The study used MPS2 and MPS3 to plan the timing of orthodontic treatment of the mandible, particularly for the treatment of skeletal Class II malocclusion, for which the optimal timing would be during the interval between stages 2 and 3 of the MPM stage.

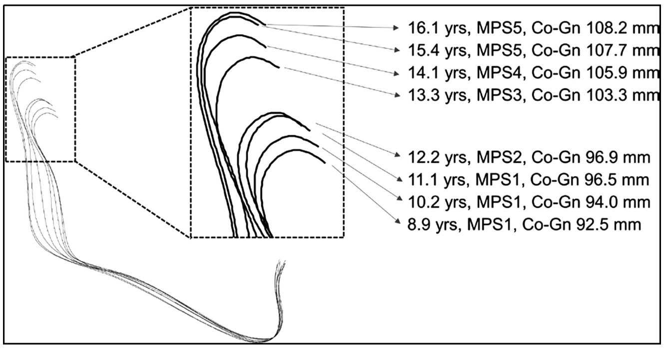


FIGURE 3. (Male) Description of mandibular growth with corresponding actual age, MPS stage. MPS: middle phalanx stage.

In recent years, many scholars have demonstrated that cervical spine bone age is highly correlated with mandibular growth. Cervical vertebral maturation methods have been studied extensively and compared in terms of reproducibility and clinical validity. The growth and development stage of the individual is determined by observing the changes in cervical spine morphology with growth on lateral cephalograms, and the morphology of the cervical spine (2nd, 3rd and 4th cervical vertebrae) is observed to evaluate the growth and development potential. The CVM method divides the morphological changes of the developing cervical spine into six stages: CS1 to CS6. It has been found that peak mandibular growth occurs between CS3 and CS4, and the modified cervical spine method has been described specifically [59] (Fig. 4).

(1) CVS1: The lower edge of the cervical vertebral body is flat in segments 2 to 4, with the vertebral body tapered in the 3rd and 4th segments. These results suggest that the peak of growth and development occurs as soon as two years later.

(2) CVS2: The slightly concave lower edge of the 2nd segment of the cervical vertebrae and the tapered shape of the 3rd and 4th segments suggest that the growth peak occurs one year later.

(3) CVS3: The lower edges of the 2nd and 3rd cervical vertebrae are concave, and the 3rd and 4th segments of the vertebrae are tapered or rectangular horizontally. These results suggest a peak of growth and development at this stage.

(4) CVS4: The lower edge of the cervical vertebral body is concave at segments 2 to 4, and the vertebral body is rectangular horizontally at the 3rd and 4th segments. This suggests that the peak of growth and development ends at this stage or has ended within one year before this stage.

(5) CVS5: The lower edge of the cervical vertebral body is concave in segments 2 to 4, and at least one of the vertebral bodies in the 3rd and 4th segments is square. These results suggest that the peak of growth and development ended one year before this stage.

(6) CVS6: The lower edge of the cervical vertebral body is concave in segments 2 to 4, and at least one of the 3rd and 4th segments is rectangular vertically, suggesting that the peak of growth and development ended at least two years before this stage.

The CVM approach has been proposed as an effective diagnostic tool to assess the association between peak adolescent growth and mandibular growth and development [60]. This can also be correlated by combining radiographs of the carpal bones with those of the cervical vertebrae (Fig. 5).

Perinetti *et al*. [57] showed that generally, the MPM and CVM methods had a satisfactory diagnostic agreement and that the MPM and CVM stages coincided well with stage 3, which corresponds to the onset of peak pubertal development, although there was slight inconsistency in stage 5, in which the 3rd segment of the phalanges appeared to mature earlier than the cervical spine. Clinically, orthodontists should have good knowledge of assessing the skeletal maturation of growing patients as it can directly or indirectly affect the diagnosis, planning, outcome, and retention protocol in orthodontic treatment.

5.2 Association of mandibular growth with the development of secondary sexual characteristics in males and females

Bishara *et al*. [61] found significant differences in size and incremental changes in cephalometric parameters between the jaws of male and female subjects after treatment in patients with skeletal Class II malocclusion; therefore, it would be better to assess growth changes in the mandible according to sex in early-treated patients. A general study [62] concluded that girls' pubertal growth peaks about 17 months before the onset of menarche, with the following main manifestations: significant breast development, the appearance of axillary hair, the darkening and extensive growth of pubic hair, and peak height growth. In boys, puberty starts later, with the following main manifestations: peak height growth, the appearance of axillary hair, the growth of a mustache on the upper lip, peak muscle growth, a reduction of subcutaneous fat, and

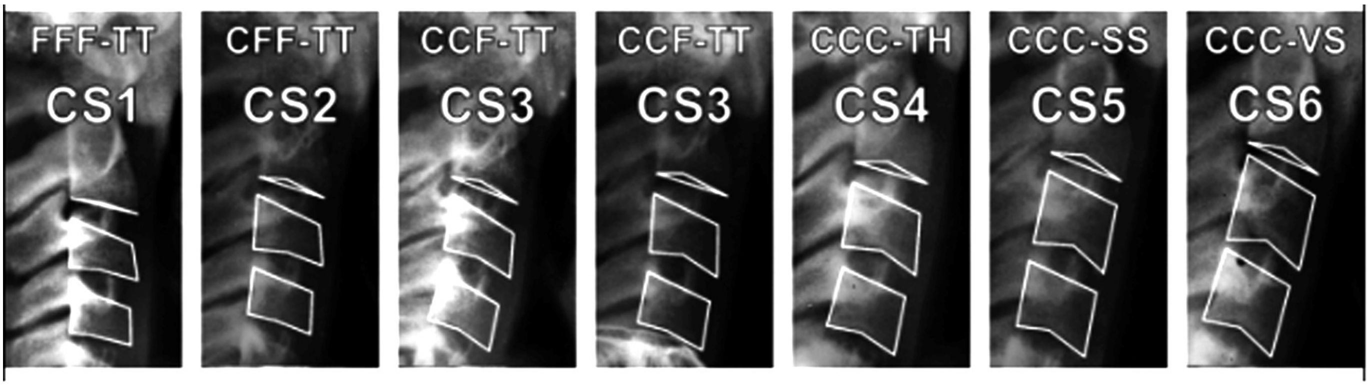


FIGURE 4. Morphological appearance and related tips of cervical spine radiograph.

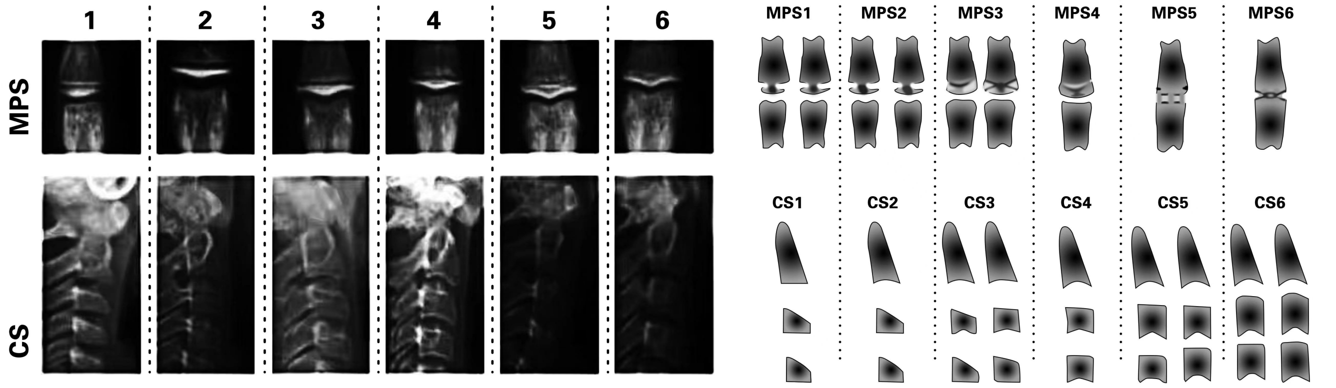


FIGURE 5. The third segment of the middle phalanx corresponds to the cervical spine maturation stages. MPS stands for MPS (middle phalanx stage) maturation stages; CS stands for cervical vertebrate maturation stages.

pubic hair distribution close to adulthood. This is also the peak of mandibular development, and although there is great variation between individuals, pubertal growth in girls occurs on average two years earlier than in boys. Although the specific reasons for this are unclear, this can have a very important impact on the timing of orthodontic treatment. Girls should start treatment earlier than boys to take advantage of their adolescent growth spurt.

5.3 Association of mandibular growth and development with dental age

The age of the teeth, determined based on their calcification, is also important in determining the peak growth of the mandible. In 2017, Buschang *et al*. [63] published a guideline assessing the growth and development of orthodontic patients; it states that there is a close relationship between tooth age and jaw growth and development, and there are links between the stage of tooth development and the eruption of teeth and between the eruption of canines and premolars, providing a reference for orthodontists to select treatment timing.

Demirjian *et al*. [64] rated all teeth on a scale of A to H. The rating is assigned by carefully following each stage's written criteria and comparing the tooth with the diagrams and radiographic images reproduced in Fig. 6. The incisors and first molars usually erupt after stage F and before stage G. Smith *et al*. [65] defined parallel root canal walls and open apical parts of mandibular canines as stage G, which is consistent with the growth spurt period. Some scholars have also used mandibular third molars to investigate the relationship with bone age, believing that third molar impaction is the result of precocious body maturation. Perinetti *et al*. [66] showed that dental age and skeletal maturity were highly correlated; although diagnostic performance for dental maturity was limited at all stages of skeletal maturity, the dental maturation stage of the mandibular teeth showed satisfactory diagnostic performance only at the prepubertal developmental stage, and there were no reliable signs of a pubertal growth spurt. Therefore, determining the clinical role of tooth maturity in assessing the timing of treatment during skeletal spurting is limited.

In general, tooth eruption varies widely. The mechanism of tooth development is not completely consistent with the bone tissue system, and tooth age does not accurately estimate the degree of development in children, although it can be referenced with other indicators.

5.4 Association between mandibular development and age

A comparison of the stages of MPM and CVM across ages is shown in Fig. 7. The mean ages were very similar, with the exception of males in stage 5, which differed by approximately 0.6 years. For both well-established methods, the actual age

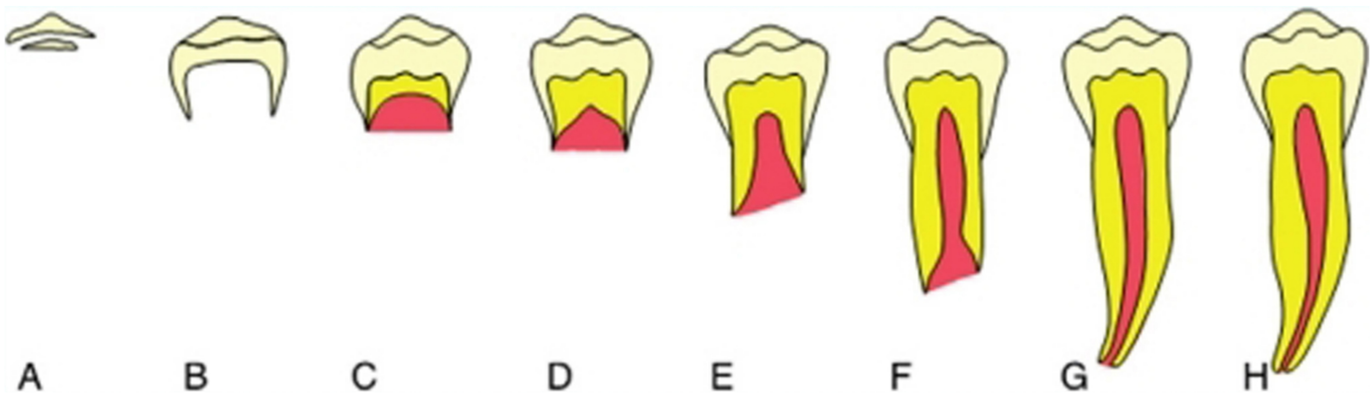
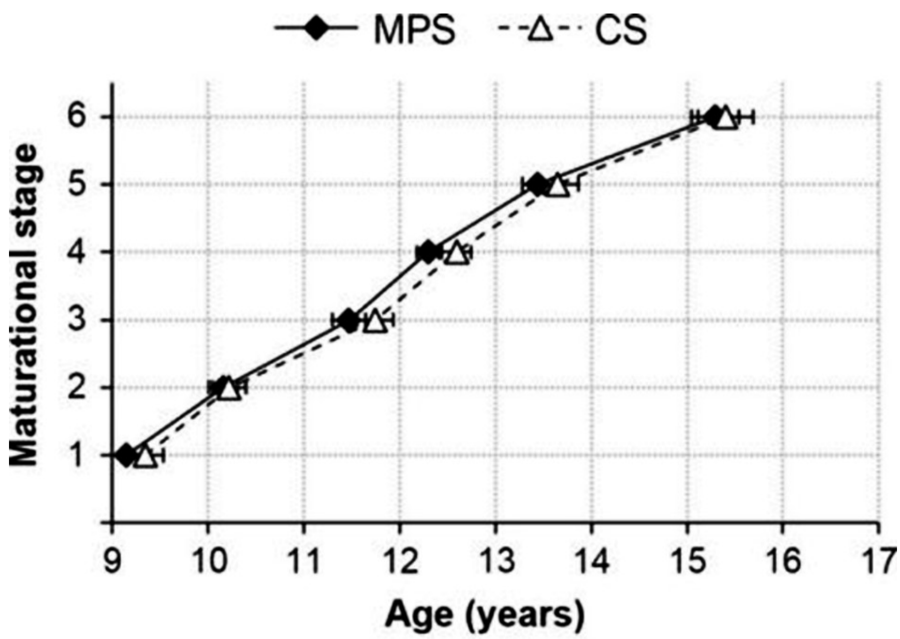


FIGURE 6. Eight stages of tooth maturation (From Demirjean *et al.* [53], 1973). Most teeth appear between stages F–G; Canines and premolars appear before or after stage G.



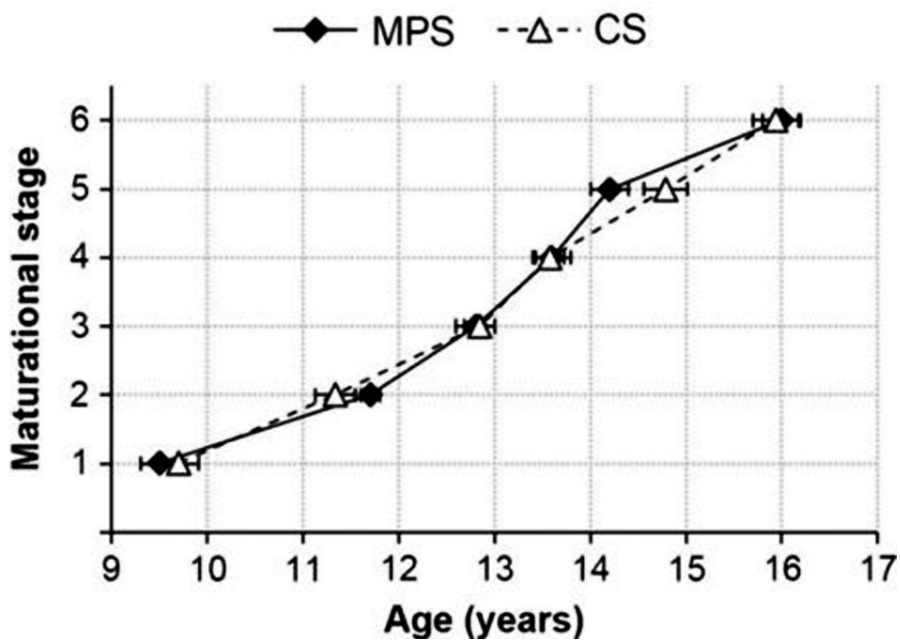


FIGURE 7. A comparison of stages of MPM or CVM across age stages. MPS: middle phalanx stage. CS: cervical vertebrate maturation stages.

difference between the sexes was approximately 0.6 to 1.5 years in two to five consecutive stages. Regardless of the maturation method used, females usually reach stages 2 to 6 one year earlier than males. It has been found that females are in the pubertal growth spurt at the age of 11 to 13 years and males at the age of 14 to 15 years [67]. However, the onset and peak of the pubertal growth spurt vary considerably among individuals in the normal population. It is extremely imprecise to determine the rapid growth period based on age, so it only indicates the possibility of a growth spurt.

6. Summary and prospects

In recent years, dentists and parents have paid increasing attention to the early prevention of malocclusion in children, and the contemporary orthodontic perspective emphasizes the importance of prevention and early correction more than before. Skeletal Class II mandibular growth demonstrates characteristics and differences between males and females, and bone growth assessment before treatment is helpful for the diagnosis of mandibular developmental morphology and the timing of early correction in adolescents with skeletal Class II malocclusion and hypoplasia of the mandible. The appropriate examination modalities should be selected, including MPS staging of ossification of the middle phalangeal metaphysis of the wrist bone, to assess the stage of morphological changes (CS1 to CS6) in the cervical spine on cervical bone radiographs; to make a judgment on the timing of jaw growth and development in conjunction with factors such as bone age, dental age, indications of secondary sex development and age; and to implement effective orthodontic treatment. Early orthodontic treatment at a time selected for effective mandibular growth and development not only maintains and reshapes the normal growth and development environment of the stomatognathic system but also contributes to the jaw health and psychological health of children. In the future, with the advancement of science and technology and the development of clinical medicine, more sensitive indicators will be developed to diagnose the early correction timing of skeletal Class II malocclusion.

AVAILABILITY OF DATA AND MATERIALS

All data generated or analyzed during this study are included in this published article.

AUTHOR CONTRIBUTIONS

BBH and XXC—conception and design. BBH—administrative support. XTL—provision of study materials or patients. All authors—data analysis and interpretation; manuscript writing; final approval of manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

An ethics statement was not required for this study type, no human or animal subjects or materials were used.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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