ORIGINAL RESEARCH

Comparison between Two Methods of Skeletal Growth Evaluation: Cervical Vertebrae Maturations and Middle Phalanx Maturation

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Abstract

Aim: Growth measurement has always been essential to identify the best time to employ orthopedic or orthodontic appliances. Optimal timing for orthodontic treatment is strictly linked to the identification of periods of craniofacial growth when treatment is more effective.

The aim of this study was to compare two different methods, middle phalanx maturation (MPM) and cervical vertebrae maturation (CVM), used to evaluate the stage of facial growth.

Materials and methods: The research data was collected from July 2018 to April 2019 at the Dental Clinic of the San Gerardo Hospital in Monza. The study included a sample of 98 patients—46 males and 52 females. For each patient, a latero-lateral teleradiography of the skull and an X-ray on the middle finger of the right hand were obtained.

The statistical analysis of the comparison of the stages of skeletal maturation obtained by the MPM and CVM methods was performed using the correlation coefficient for ranks of Spearman.

Results: A descriptive statistical analysis of the entire sample of 98 patients was performed (mean age of 12.2 years and median of 12.2 years). The average age of females in every single stage of MPM was significantly lower than the average age of males. Of the total sample, 87 patients (88.8%) showed complete agreement between the two methods.

Conclusion: The results obtained from the statistical analysis of this study allowed us to confirm a satisfactory agreement between the two methods.

The intermediate phalanx method is a valid and alternative indicator to CVM for the identification of the puberty growth peak. We can, therefore, consider the MPM method a valid indicator of skeletal maturity.

Keywords: Cervical vertebrae maturation, Facial growth, Growth spurt, Middle phalanx maturation, Orthodontic diagnosis.

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Introduction

The "time factor" plays a crucial role in determining the final shape and size of each somatic structure of the body, during its growth and development. Even in orthodontics and dentofacial orthopedics, the timing of treatment is as important as the choice of the correct therapy.[1]

The continuous search for improvements in all the fields of dentistry constantly leads to the development of new techniques.[2–8] In orthodontics, before starting treatment, it is necessary to evaluate the patient's skeletal maturation phase, paying particular attention to the pubertal growth peak. During puberty, in fact, the growth rate is greater than in any period after childhood enhancing the possibility of restoration of skeletal disharmonies.[1]

Maxilla and mandible have different scheme of maturation—in fact, in the maxilla, bone formation last until the fusion of the sutures that happens after puberty (namely sutural growth); so, maxillary growth potential mainly involves the prepubertal stage.[9,10] Instead, in the mandible, bone formation is initially limited and progressively intensifies reaching a peak during puberty; after that, it gradually reduces until its complete maturation.[11,12] For these different growth models, all interceptive therapies using an orthopedic appliance must be performed at specific times—transverse maxillary expansion has to be realized at a young age taking advantage of the incomplete fusion of the sutures; instead, the correction of a class II malocclusion, which stimulates forward repositioning and mandibular growth, is best given during puberty. In fact, numerous studies have shown that establishing the growth spurt (the most favorable and responsive growth period) enhances orthodontic treatments, regardless of the device used.[1,13,14]

From a clinical point of view, it is necessary to identify the beginning of the pubertal growth peak, which on average lasts for 1–2 years and starts in a very variable age range, generally

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from 9 to 15 years.[15] For this reason, the chronological age cannot be used as a parameter to establish the skeletal maturation age and consequently not even for the timing of functional therapy.[16] Over time, different methods with high inconstancy and low predictability have been proposed for assessing skeletal age, such as the dental age, the secondary sexual characters, and standing height.[17,18] An essential method in orthodontics is CVM, which is based on the correlation between bone age and cervical vertebrae (C2, C3, and C4), visible on the lateral teleradiography of the head.[11,19]

In the 1970s, Fishman drew up a method for determining skeletal age by observing a hand and wrist radiograph.[20] Recently has been proposed a further classification that uses radiography of the middle phalanx of the third finger (through intraoral dental radiography). This method, called MPM,[21] is based on the ossification of the metaphysis with the epiphysis and consists of six stages, or middle phalanx stages (MPS), such as in the CVM—MPS1 and 2 occur during the prepubertal period; MPS3 coincides with the pubertal growth spurt and with the best time to start functional treatment; MPS4 corresponds to the growth deceleration phase; and MPS5 and 6 are postpubertal stages.

The MPM method originates from the need to find a simple and rapid way to monitor the orthodontic patient's growth; if the diagnosis occurs in a prepubertal growth phase as in several cases, the therapy for class II must be postponed. According to orthodontic radiography guidelines,[22–24] a lateral radiograph cannot be made exclusively for the purpose of calculating skeletal age; this has led to the development of the MPM method.[25,26]

The aim of this retrospective study was to compare the two methods, MPM and CVM, used to establish the stage of skeletal maturation verifying a statistical agreement between the stage of maturation of the middle phalanx of the third finger and the cervical vertebrae.

Materials and Methods

Data were collected from July 2018 to April 2019 at the orthodontics department of the Odontostomatology Clinic of San Gerardo Hospital in Monza. All patients and parents provided written informed consent to the treatment protocol. We established the following inclusion criteria—(1) age between 6 and 18 years, (2) Caucasian ethnicity, (3) good general health status, (4) no nutritional problems, (5) absence of hormonal or growth problems, (6) absence of anomalies in the finger and vertebrae, (7) absence of trauma history in the cervical region or right hand, and (8) latero-lateral teleradiography starting from maximum 20 days from the date of examination.

Our sample consists of 98 patients—46 males and 52 females.

All patients carried out a teleradiography and at the next appointment, planned at a distance not exceeding 20 days, an X-ray on the middle finger of the right hand was taken.

Radiographic Recordings

The radiographic collection was performed with a standard method, previously reported by Abdel Kader.[27] Patients were exhorted to place the right hand with the fingers apart and with the palm facing down on a flat surface; the third finger must be placed parallel to the long axis of the intraoral radiograph so that the metaphysis and epiphysis of the middle phalanx are well straight and centered on the intraoral X-ray film of standard size (30 × 40 mm). Once the patient's hand is positioned correctly, the cone of the radiograph is placed in slight contact with the middle phalanx and perpendicular to the film. Radiography parameters were 70 kV, 7 mA, and 0.15 seconds of exposure time. All radiographs were taken by the same operator.

Patients were invited to carry out teleradiographies at external radiological centers. Teleradiographies that presented a date of execution prior to 20 days from the date of examination were discarded from the study, as well as low-quality radiographs.

Thereafter, all patients were evaluated and classified according to the maturation stage for both the MPM and CVM methods.

MPM Method

The MPM method consists of six stages each named MPS as follows:

- Middle phalanx stage (MPS) 1—this stage indicates the presence of an epiphysis smaller or equal to the metaphysis, without fusion. Onset time—1 year before a growth spurt.
- Middle phalanx stage (MPS) 2—this stage indicates an epiphysis equal to the metaphysic; a demarcation line is evident. Onset time—1 year before a growth spurt.
- Middle phalanx stage (MPS) 3—epiphysis is equal or bigger than the metaphysic; the presence of initial capping in the metaphysic. Absence of fusion. Onset time—growth spurt.
- Middle phalanx stage (MPS) 4—in this phase starts fusion; epiphysis capping remains evident. Onset time—subsequent to growth spurt.
- Middle phalanx stage (MPS) 5—in this stage fusion is still incomplete. Onset time—end of a growth spurt.
- Middle phalanx stage (MPS) 6—in this stage has been reached a total fusion of epiphysis and metaphysis. Onset time—end of a growth spurt.

Each stage of this method was evaluated and attributed by the same operator analyzing the morphology and the relationship between metaphyses and epiphyses.

CVM Method

The CVM method includes a classification of six stages called cervical stage (CS) and defined as follows:

- Cervical stage (CS) 1—C2, C3, and C4 show a flat border and a trapezoid shape. Onset time—2 years before mandibular growth peak.
- Cervical stage (CS) 2—C2 shows a concavity. Onset time—1 year before mandibular growth peak.
- Cervical stage (CS) 3—C2 and C3 show concavities. Onset time—1 year before mandibular growth peak.
- Cervical stage (CS) 4—C2, C3, and C4 all show concavities. Onset time—1 or 2 years before mandibular growth peak.
- Cervical stage (CS) 5—C2, C3, and C4 still show concavities but C3 or C4 show a squared shape. Onset time—at least 1 year before mandibular growth peak.
- Cervical stage (CS) 6—C2, C3, and C4 still show concavities but C3 or C4 show rectangular shapes. Onset time—at least 2 years before mandibular growth peak.

Statistical Analysis

The Gnu Regression, Econometrics, and Time-series Library 2019a software was used for the descriptive statistical analysis of the sample, and the statistical analysis for the comparison of skeletal maturation stages obtained by the two methods was performed using the Spearman's correlation coefficient (r_s), with a *p*-value of 0.05.

Results

Our sample presented an average age of 12.2 years, with a minimum of 6.6 and a maximum of 17.6 years, with a standard deviation of 2.58 (Fig. 1).

The average age for all stages of maturation was also calculated, according to MPM—9.15 and 8.81 years in MPS1, 11.71 and 9.6 years in MPS2, 12.68 and 11.86 years in MPS3, 13.36 and 12.68 years in MPS4, 15.64 and 13.42 years in MPS5, and 15.74 and 14.93 years in MPS6, for males and females, respectively. The average age of females in every single stage of MPM is significantly lower than the average age of males due to previous female skeletal maturation.

In this study, the average age at which both males and females reached the puberty growth spurt is around 12 ± 0.5 years, during the MSP3 stage.

A first comparative analysis of the MPM and CVM methods is represented by the graph of patients' years/stages (MPS or CS) of skeletal maturation, for each method (Figs 2 and 3).

The two resulting straight lines are very similar and through this scheme of representation, it is possible to observe the existence of direct proportionality between stage and age and to notice that the distribution of the patients between the two methods is homogeneous, thus allowing us to perform a significant comparison.

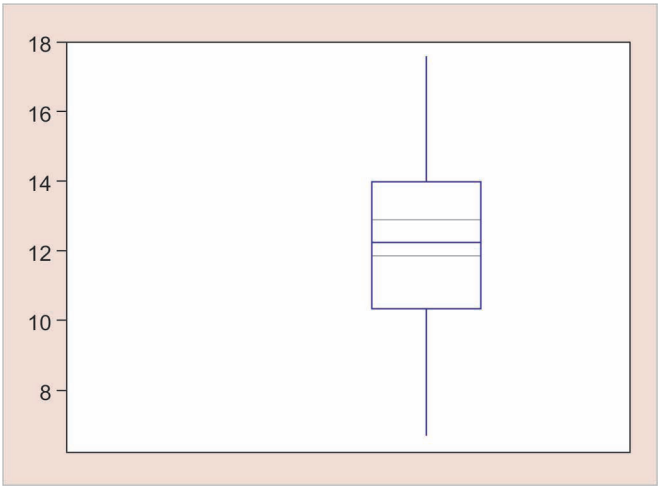

Fig. 1: Box plot of age distribution

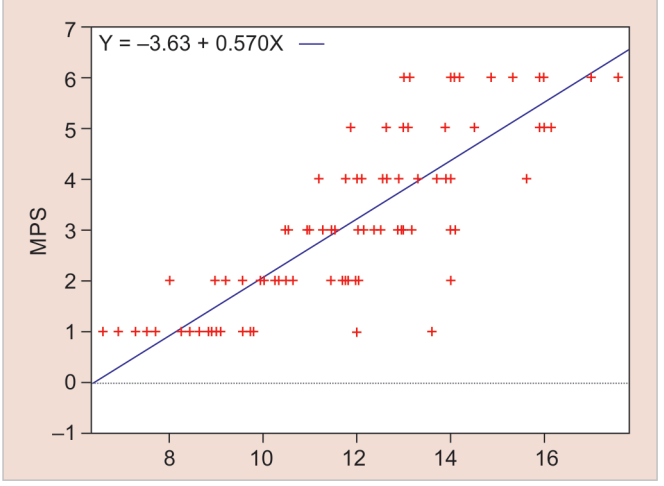

Fig. 2: Middle phalanx stage

Through the nonparametric correlation test, it was possible to calculate the Spearman's coefficient, in order to verify the hypothesis of an association between the maturation stages of the two methods, MPM and CVM. The variables taken into consideration, for this test, are the MPS and CS stages found for each patient. The correlation coefficient between the two methods of evaluation of skeletal maturation was 0.972 (p-value < 0.05) for the complete sample, 0.979 (p-value < 0.05) for males, and 0.973 (p-value < 0.05) for females.

Moreover, 87 patients (88.8%) showed a complete agreement between the skeletal maturation stage obtained with the MPM and CVM method; 11 patients (11.2%) presented a discrepancy. In particular, nine patients (9.2%) differed for one stage of maturation and only two patients (2%) differed for two stages of maturation. The overall correspondence was 86.96 and 90.38%, respectively for males and females.

The detailed distribution related to the percentage of agreement between each stage of MPM and CVM is summarized in Table 1.

Middle phalanx maturation (MPM) and CS coincided with 80.0% in MPS5/CS5 and 100.0% in MPS1/CS1.

Discussion

In our study, pubertal growth spurt occurred on average at 11.86 years for females and 12.68 years for males, similar to previously reported data.[15,28,29]

In particular, the age of growth spurt presented a high variability with a minimum of 10.5 years and a maximum of 14.1, confirming that chronological age remains an unreliable parameter.[1,20,30]

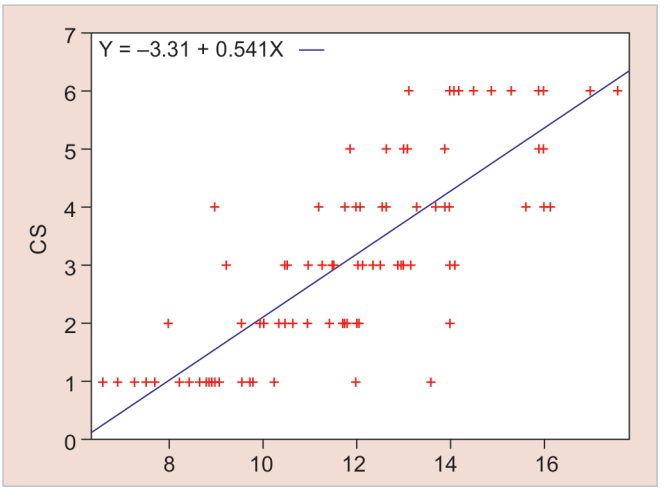

Fig. 3: Cervical stage

Table 1: Percentage of agreement between each stage of MPM and CVM

	CS1	*CS2*	*CS3*	*CS4*	*CS5*	*CS6*	*Total*
MPS1	100.0%						19
MPS2	5.9%	82.4%	5.9%	5.9%			17
MPS3		5.0%	90.0%	5.0%			20
MPS4			7.1%	92.9%			14
MPS5				10.0%	80.0%	10.0%	10
MPS6				5.6%	11.1%	83.3%	18
Total	20.4%	15.3%	20.4%	17.3%	10.2%	16.3%	98

The CVM method represents a reliable model of evaluation of skeletal maturation, establishing a possible relationship between the general growth curve and that of the craniofacial structures, in particular with the mandibular curve.[31,32] Moreover, through a randomized clinical trial, the CVM method was approved as a valid indicator for the choice of the correct timing of functional treatments, especially in patients with mandibular retrusion, in order to obtain advantageous skeletal results.[33]

A possible problem of the CVM method is reproducibility because it was noticed that the stage agreement percentage is lowered to 50% when teleradiography is evaluated by two different observers, while it increases to 63% when the same operator evaluates the same radiograph at different times.[34]

Nestman et al.[35] reported that the main difficulty encountered by the operator concerned the evaluation of C3 and C4 body shapes; despite this, the reproducibility demonstrated in this study was satisfactory.

We can therefore assume that to have a greater reproducibility of CVM, a good experience of the operator who assigns the stage of skeletal maturation is necessary.

In addition to specific training, a lateral teleradiography of the head is required to establish the CVM stage, which is usually available in the pretreatment diagnostic phase but generally, the treatment of class II cases should be postponed for an undefined period of time until the pubertal spurt. An additional teleradiography for the reassessment of the growth stage is not included in recent guidelines.[22–24]

Moreover, the protective collar (for the patient's radioprotection) could interfere with the CVM method.[23]

The hand and wrist radiography for the HWM method leads to minor radiation exposure,[23] but anyway requires additional exposure to X-rays and also the use of a specific radiograph.

To circumvent this limitation Perinetti et al.[21] proposed the MPM method, a simplified Fishman method; MPM method can be repeated to observe the evolution of ossification events involving epiphysis and metaphysis; in fact, it limits X-rays exposure to a restricted area of the finger and allows the use of a low radiation dose, starting from 7 mA for an exposure time of fewer than 0.1 seconds. Moreover, the radiograph of the middle phalanx can be easily realized with a common intraoral X-ray with a self-developing film or a standard 3 × 4 cm periapical sensor, easily available.

The comparison between the MPM and CVM methods was carried out using the Spearman's coefficient, which is 0.972 for the total sample. Since this index is very close to +1, this shows in our study, we demonstrate a high statistical correlation between the two methods examined (Spearman's coefficient 0.972 for the total sample, 0.973 for females, and 0.979 for males)—these results are very close to those obtained by Perinetti et al.[21] and Hegde et al.[36]

In our study, we noticed that in 87 patients there was a complete agreement between the two methods, while in 11 patients there was a discrepancy; these results confirm what was noticed by Perinetti et al.[21]

The lower agreement is in the postpubertal stages (MPS5/CS5 and MPS6/CS6). In particular, "older patients," such as 16-year-old males, showed a complete fusion of the epiphysis with the metaphysis (without the possibility of recognizing the edge of the epiphysis), while the morphological maturation of the bodies of cervical vertebrae is delayed, as reported also by Perinetti et al.[21] that hypothesized an easier detectability of small alterations in the middle phalanx than in the cervical vertebra.

Furthermore, we subdivide the sample into two groups: more or <12 years. It was noticed that the agreement for those under 12 (three patients) was 100% (Table 2); while in patients over 12 years (38 patients), the value decreases to 77.8% among MPS5/CS5 (Table 3). If this group of 38 patients is distinguished by gender, we observed that in males the percentage dropped further to 50% between MPS5/CS5 (Table 4); on the contrary, the females showed a very good agreement (Table 5).

From a clinical point of view, the detection of postpubertal growth should be established in the MPS6 stage rather than MPS5 (particularly in males).

Ideally MPS 2 and 3 stages should have exact durations so that therapies could be planned at specific times. In our study, we noticed that MPS2 lasts about 1 year in females and 2 years in males, while MPS3 lasts about 1 year for both, without the possibility to predict how long a patient remains in a certain stage. According to Baccetti et al.[1], the stages of the CVM method from CS 2 to 5 have an approximate duration of 1 year each, but in a recent longitudinal study,[37] it is observed that the duration of the stages is unpredictable and could vary, resulting in the impossibility of programming therapies.

Therefore, to allow the monitoring of skeletal growth phases, a simple staging method, such as MPM is needed, exposing the patient to low doses of radiation.

Table 2: <12 years

	CS4	*CS5*	*CS6*	*Total*
MPS4	100.0%			2
MPS5		100.0%		1
MPS6			–	0
Total	66.7%	33.3%		3

Table 3: >12 years

	CS3	*CS4*	*CS5*	*CS6*	*Total*
MPS4	9.1%	90.9%			11
MPS5		11.1%	77.8%	11.1%	9
MPS6		5.6%	11.1%	83.3%	18
Total	2.6%	31.6%	23.7%	42.1%	38

Table 4: >12-year-old males

	CS3	*CS4*	*CS5*	*CS6*	*Total*
MPS4	16.7%	83.3%			6
MPS5		25.0%	50.0%	25.0%	4
MPS6		12.5%	12.5%	75.0%	8
Total	2.6%	31.6%	23.7%	42.1%	18

Table 5: >12-year-old females

	CS4	*CS5*	*CS6*	*Total*
MPS4	100.0%			5
MPS5		100.0%		5
MPS6		10.0%	90.0%	10
Total	25.0%	30.0%	45.0%	20

Middle phalanx maturation (MPM) method requires the examination of the right hand; a recent comparison between the left and right hands by Gracco et al.[38] reported that in patients with MPS2, an additional X-ray should be performed on the left hand to increase diagnostic accuracy in detecting puberty growth spurt. In particular, of the patients in stage 2, 17.1% presented MPS3 in the left hand. In all other phases, no further investigations are necessary because a total agreement was found between the two hands.

The present study shows that the MPM method is a reliable and easy-to-interpret method for evaluating skeletal growth, which exposes the patient to low doses of radiation.

Conclusion

The present study shows that the MPM method is a reliable and easy-to-interpret method for evaluating skeletal growth, which exposes the patient to low doses of radiation.

We observed a satisfactory agreement between CVM and MPM methods, establishing MPM as a valid and alternative method to CVM because it allows monitoring growth without requiring additional lateral teleradiography and overcoming the limitations of CVM when C2–4 cervical vertebrae are not clearly visible.

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