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Assessment of the third finger middle phalanx maturation stages: A study of repeatability and diagnostic agreement

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ABSTRACT

Introduction: Data regarding the repeatability of the third finger middle phalanx maturation (MPM) method is still lacking.

Aim of the study: This study evaluated both the repeatability and diagnostic accuracy of the visual assessment of the MPM stages.

Materials and methods: Ten operators were given detailed instructions of the 5-stage MPM method and were asked to stage 80 cases, which included radiographs of an equal number of all 5 MPM stages. Radiographs of the third finger were created by cropping hand-wrist radiographs of the Burlington Growth Study, ensuring the inclusion of several borderline cases. Such assessment was repeated in two sessions (T1 and T2) 4 weeks apart.

Results: For both the sessions, overall agreement and kappa coefficients were above 80% and 0.86, respectively. Most of the disagreements were seen for stages 1 and 2 with overall mean scores between the sessions being 29.7% and 39.4%, respectively. With only 4 exceptions (out of over 1,600 recordings), 1-stage apart disagreements were seen. Overall diagnostic accuracy ranged from 83.7% for MPM stage 2 (T1) to 99.3% for MPM stage 5 (T1).

Conclusion: The MPM method has a satisfactorily level of repeatability and diagnostic agreement. About 1 case out of 5 remains misclassified, disagreement is mostly limited to 1-stage apart, with stage 2 being the most critical.

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INTRODUCTION

When dealing with skeletal disharmonies, the precise identification of skeletal maturity, with particular regard to the onset of the pubertal growth spurt, has major clinical implications in terms of treatment efficiency. [1,2] Several growth indicators have been proposed to identify phases of skeletal maturity, [1,3-6] including the cervical vertebral maturation (CVM) method [7] that has gained much attention over the last two decades. Nevertheless, the CVM method has been reported to have unsatisfactorily diagnostic accuracy in the identification of mandibular growth peak, [8] variable duration of the stages [9,10] and failure in attaining post-pubertal stages in all subjects. [11] More recently, the use of the sole third finger middle phalanx maturation (MPM) method has been suggested [12] as a valid alternative. This 5-stage method has good diagnostic capability in detecting mandibular growth peak, [13] and it is gaining growing consideration in clinical practice. [14,15]

To date, no investigation has evaluated the repeatability of the MPM method. Yet, this represents a relevant piece of information considering how decision-making about treatment timing is strictly dependent upon proper staging. Moreover, data on the diagnostic agreement, i.e. agreement of the raters with a reference standard, in the assessment of the MPM stages would also have major clinical relevance.

By using files from the Burlington Growth Study, the present study aimed at the evaluation of the MPM method repeatability (among and within raters) and diagnostic agreement with a reference standard. The existence of any difference among the various MPM stages has also been investigated.

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MATERIALS AND METHODS

Selection of the cases and films

Cases selected for the present study constitutes a subset of those included in a previous investigation.[13] Films were selected from the records of the Burlington Growth Study, extracted from the American Association of Orthodontists Foundation (AAOF) Craniofacial Growth Legacy Collection (www. www.aaoflegacycollection.org). Subjects were selected for inclusion if they had at least 7 annual hand-and-wrist radiographs from 9 to 16 years, with further details reported elsewhere. [13] The screened sample included a total of 32 cases (15 females and 17 males) selected to provide a total of 80 radiographs (40 from males and 40 from females) (Table 1). In particular, 16 radiographs per MPM stage were used for the study. Each subject provided a single good-quality radiograph per MPM stage. In most of the cases, the included radiographs had a stage with the corresponding previous or subsequent radiograph showing a different stage (Table 1). The staging of these radiographs (reference standard) was performed by an expert operator and checked for accuracy by a second investigator, as previously reported. [13] Moreover, the longitudinal analysis of the radiographs within the same cases, allowed for a more accurate staging for the reference standard.

Table 1. The middle phalanx maturation stages according to the different ages of the analyzed subjects with the corresponding radiograph selection.

ID	Age							
	9 yrs	10 yrs	11 yrs	12 yrs	13 yrs	14 yrs	15 yrs	16 yrs
183, M	1	1	1	1	1*	2	NA	3*
185, M	1	1	1	1	2*	3*	NA	5*
231, M	1	1	1	2*	3*	4*	NA	5*
266, M	1	1	1	1	1	2*	NA	3
289, M	1	1	1	1	1*	2	4*	5
357, M	1	1	1	1	1*	2	NA	5*
366, M	1	1	1	1	2	2	NA	4*
392, M	1	1	1	1	1*	2	NA	4*
399, M	1	1	1	1	1*	2	NA	4*
544, M	1	1	1	2*	3*	4*	5*	5
636, M	1	1	1	1	1	2*	3*	3
637, M	1	1	1	1	1*	2	NA	5*
706, M	1	1	1	1*	2	2	3*	4*
742, M	1	1	1	1*	2	2*	3*	5
763, M	1	1	1	1	2*	3	NA	5*
863, M	1	1	1	1	2*	3*	5	5*
871, M	1	1	1	2	2	4*	5*	5
153, F	1	3	4	4*	5	5	NA	5
163, F	1	1	1*	2*	3*	4*	NA	5
188, F	1	2*	3*	4*	5	5*	NA	5
198, F	1*	2	2	4	4	5*	NA	5
208, F	1	2*	3*	4*	5*	5	NA	5
316, F	1	1*	2	3	5	5*	NA	5
321, F	1	2	2	3*	4*	5*	NA	5
391, F	1	1*	2*	3	3	4	NA	5
487, F	1	2	2	3*	4*	5*	NA	5
595, F	2	3	3	4	4	5*	NA	5
602, F	1	1*	2*	3*	4	4	NA	5
619, F	1	1*	2*	3*	4	5*	NA	5
631, F	1	1*	2	2	3*	4*	NA	5
855, F	1	1	2*	3	4*	4	NA	5
1391, F	1	1	1*	NA	2*	3	NA	5

M, Male; **F**, female; **NA**, not available; *, selected radiograph. Data from Perinetti et al.[13]

Raters

A total of ten raters not participating in the design or data analysis of this investigation were enrolled. Most of these raters had minimal or no previous experience in the use of the MPM method. Each rater was given written instructions (Table 2) and a detailed figure of the different staging according to Perinetti et al.,[13] including diagrams of morphological transitions between stages (Figure 1). Two random orders of radiographs were generated, and staging was performed individually by the raters in two sessions (T1 and T2) 4 weeks apart.

Statistical analysis

Repeatability assessment of the MPM stages evaluated agreement: 1) of raters with the reference standard for each session; 2) between the two sessions within each rater; and 3) among raters within each session. Moreover, a diagnostic agreement analysis of the raters with the reference standard within each session was also performed.

The percentages of full agreement of each rater and the reference standard (within each session) was calculated, along with the percentages of full repeatability between the two sessions, both within each rater and for the whole group. The percentage of disagreement according to each MPM stage was also derived as an overall mean value of the two sessions for the whole group of raters.

To determine the degree of agreement between each rater and the reference standard (within each session), along with the degree of repeatability between the two sessions and within each rater, linear weighted kappa coefficients [16] were used and presented as mean and 95% confidence interval (CI). The following standards for strength of agreement for the kappa coefficient were followed: 0.01-0.20, slight; 0.21-0.40, fair; 0.41-0.60, moderate; 0.61-0.80, substantial; and >0.80 almost perfect. [17]

Table 2. Description of the different third finger middle phalanx maturation stages. For stages 1 to 3, in case of asymmetry, the most mature side is used to assign the stage (see also Figure 2). Description according to Perinetti et al.[13]

Stage 1: Epiphysis is narrower than the metaphysis, or epiphysis as wide as metaphysis but with both tapered and rounded lateral borders. Attained before the onset of the mandibular growth peak
Stage 2: Epiphysis at least as wide as the metaphysis with sides increasing thickness and showing a clear line of demarcation at right angle. Attained at coincidence with the onset of the mandibular growth peak
Stage 3: Epiphysis is either as wide or wider than the metaphysis with lateral sides showing an initial capping towards the metaphysis. Epiphysis and metaphysis are not fused. Attained at coincidence of the maximum mandibular growth peak
Stage 4: Epiphysis begins to fuse with the metaphysis although contour of the former is still clearly recognizable. Attained after the mandibular growth peak
Stage 5: Epiphysis totally fused with the metaphysis

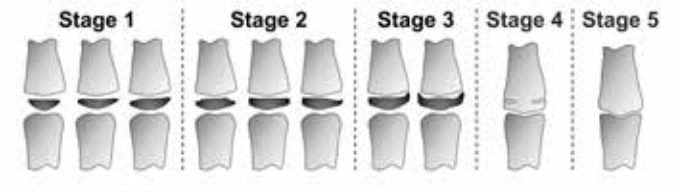

Figure 1. The diagram of the stages of the third finger middle phalanx maturation method. For description, see Table 1. Modified from Perinetti et al.[13]

For the whole group of raters, within each session, inter-rater agreement was assessed by the Kendall's W coefficient of concordance. Moreover, within each MPM stage, a more comprehensive diagnostic performance analysis was performed, including sensitivity, specificity, positive and negative predictive values, and accuracy [18] and presented as mean and 95% confidence interval (CI). Finally, when calculating the overall means for these parameters, including the kappa values, the paired nature of that data was taken into account.

The SPSS software 20 (SPSS® Inc., Chicago, Illinois, USA), MedCalc® software 12.3.3.0 (MedCalc Software, Mariakerke, Belgium) and Comprehensive Meta-Analysis, version 2 (BiostatTM, Englewood, New Jersey, USA) were used to perform the statistical analyses. A p-value less than 0.05 was used for the rejection of the null hypothesis.

RESULTS

Representative radiographs, for each MPM stage according to the reference standard, are shown in Figure 2. The percentages of full agreement between each rater and the reference standard and within each rater are summarized in Table 3. The full agreement with the reference standard as %(n) with the reference standard for each rater ranged from 78.8% to 87.5%. The overall agreements of the whole group of raters with the reference standard were 82.5% and 80.5% for T1 and T2, respectively, and of 82.4% for the intra-rater repeatability.

The weighted kappa coefficients between each rater and the reference standard and within each rater are summarized in Table 4. The kappa coefficients as mean (95% CI) with the reference standard for each rater ranged from 0.83 (0.77-0.90) to 0.92 (0.87-0.97). The overall kappa coefficients of the whole group of raters with the reference standard were 0.89 (0.83-0.94) and 0.87 (0.81-0.93) for T1 and T2, respectively, and of 0.87 (0.81-0.93) for the intra-rater repeatability.

The Kendall's W coefficients of concordance for inter-rater agreement were 0.95 and 0.94 ($p < 0.001$) for sessions 1 and 2, respectively. In all the cases, a 1-stage-apart disagreement was seen (with only 4 exceptions out of a total of 1,600 recordings among both sessions). Most of the disagreements were seen for stages 1 and 2 with overall between sessions mean scores of 29.7%, 39.4%, 16.6%, 8.8% and 0.6% for MPM stage 1, 2, 3, 4, and 5, respectively.

For the whole group of raters, diagnostic agreement with the reference standard is summarized in Table 5. All the diagnostic parameters were generally similar between the two recording sessions, with the lowest values seen for the MPM stage 2. In particular, sensitivity ranged between 58.8% for MPM stage 2 (T1) to 100% for MPM stage 5 (T1); specificity values ranged from 89.1% for MPM stage 2 (T2) to 99.4% for MPM stage 4 (T1); PPVs ranged from 58.9% for MPM stage 2 (T1) to 98.0% for MPM stage 4 (T1); NPVs ranged from 89.9% for MPM stage 2 to 100% for MPM stage 5 (T1); accuracy ranged from 83.7% for MPM stage 2 (T1) to 99.3% for MPM stage 5 (T1).

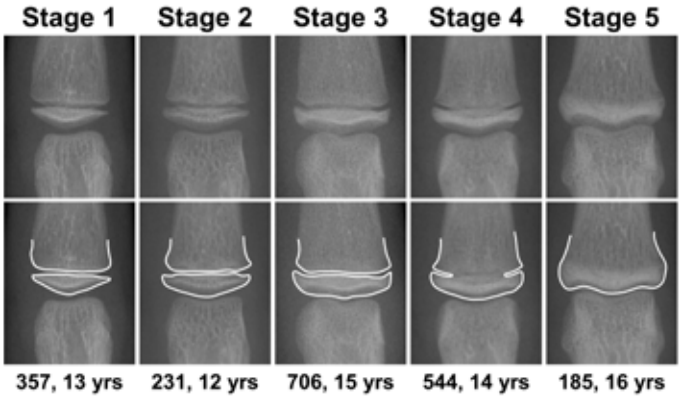

Figure 2. Representative radiographs for each third finger middle phalanx maturation stage according to the reference standard.
Middle phalanx maturational stages showed without (upper) and with (lower) corresponding tracing. Numbers at the bottom represent the Burlington Growth Study files subjects and age.

Table 3. Percentages of agreement with the reference standard according to the recording sessions (T1 and T2), and for intra-rater agreement between the recording sessions for each rater.
Overall results presented as means of percentages (n) among raters. n=16 for each MPM stage.

Rater	With reference standard		Intra-rater
	T1 % (n)	T2 % (n)	T1-T2 % (n)
1	87.5% (70)	85.0% (68)	86.3% (69)
2	86.3% (69)	80.0% (64)	76.3% (61)
3	83.8% (67)	80.0% (64)	81.3% (65)
4	82.5% (66)	76.3% (61)	76.3% (61)
5	80.0% (64)	75.0% (60)	81.3% (65)
6	78.8% (63)	82.5% (66)	81.3% (65)
7	80.0% (64)	81.3% (65)	82.5% (66)
8	82.5% (66)	83.8% (67)	88.8% (71)
9	82.5% (66)	78.8% (63)	88.8% (71)
10	81.3% (65)	82.5% (66)	81.3% (65)
Overall	**82.5% (66.0)**	**80.5% (64.4)**	**82.4% (65.9)**

Table 4. Weighted kappa coefficients for the inter-rater agreement with the reference standard according to the sessions (T1 and T2), and for intra-rater agreement between the recording sessions for each rater.
Overall results presented as means (95% CI) among raters. n=16 for each MPM stage.

Rater	With reference standard		Intra-rater
	T1 mean (95 %CI)	T2 mean (95 %CI)	T1-T2 mean (95 %CI)
1	0.92 (0.87-0.97)	0.91 (0.85-0.96)	0.90 (0.85-0.96)
2	0.91 (0.86-0.96)	0.86 (0.80-0.93)	0.84 (0.77-0.90)
3	0.90 (0.84-0.95)	0.87 (0.82-0.93)	0.88 (0.82-0.94)
4	0.89 (0.83-0.95)	0.85 (0.79-0.91)	0.85 (0.79-0.91)
5	0.87 (0.82-0.93)	0.83 (0.77-0.90)	0.86 (0.79-0.93)
6	0.87 (0.81-0.93)	0.89 (0.84-0.94)	0.88 (0.83-0.94)
7	0.88 (0.82-0.93)	0.88 (0.83-0.94)	0.88 (0.83-0.94)
8	0.89 (0.84-0.95)	0.89 (0.84-0.95)	0.93 (0.88-0.97)
9	0.89 (0.83-0.94)	0.85 (0.79-0.92)	0.91 (0.86-0.97)
10	0.88 (0.82-0.94)	0.87 (0.81-0.94)	0.88 (0.82-0.94)
Overall	**0.89 (0.83-0.94)**	**0.87 (0.81-0.93)**	**0.87 (0.81-0.93)**

DISCUSSION

The present study analyzed the diagnostic accuracy and repeatability of the MPM method showing an overall satisfactory repeatability and diagnostic agreement, although the MPM stage 2 appears to be the most critical.

The MPM method used herein was the same recently reported to have an overall diagnostic accuracy of 91% in the assessment of imminent mandibular growth peak.[13] Since this is the first study evaluating the repeatability and diagnostic agreement of the MPM method, a comparison with previous data is not possible. As reported for the CVM method, a different degree of repeatability may be retrieved according to the different maturation stages.[19,20] Therefore, to obtain relevant clinical implications, an investigation has to include an equal number of radiographs for each maturation stage and assess the repeatability of each of them. Moreover, a comprehensive study on a given growth indicator should also include a reference standard to evaluate the capability of the raters to perform a correct staging (diagnostic agreement), other than being limited to the repeatability among or within raters. To accomplish these goals, the present study used a total of 80 cases equally distributed among the 5 MPM stages. The availability of longitudinal radiographs, with about 12 months intervals between consecutive recordings, from the Burlington Growth Study allowed for an accurate staging (reference standard) by the analysis of middle phalanx maturation over time within each subject. Finally, a full transparent reporting of the reference standard (Table 1) has been followed by using known longitudinal radiographs available through the AAOF Legacy Collection.

The repeatability of the MPM method was generally high, with overall agreements above 80% (Table 3) and weighted kappa coefficients above 0.87 (Table 4), with most of the disagreement with the reference standard seen for MPM stages 1 and 2 (29.7% and 39.4%, respectively). Previous investigations on the CVM method reported percentages of the agreement below 50%,[21,22] or 77%.[20] Of note, percentages of agreement and weighted kappa coefficients (with the reference standard and intra-rater) were generally similar among the raters (Tables 3 and 4). This evidence was also confirmed by the high Kendall's coefficients (above 0.94) retrieved herein, which were greater than that of the CVM method, reported to be between 0.72 and 074,[19] or about 0.90.[20] Since the MPM method includes different stages, in case of disagreement the number of stages apart could also have clinical implications. In the present study, all of the disagreements (with only 4 exceptions) were due to only 1 stage apart, thus limiting the entity of misdiagnosis in case of erroneous staging. On the contrary, relevant percentages of disagreement up to 3 stages apart have been reported for the CVM method.[20-22]

Diagnostic agreement of each rating session showed generally high scores, especially for the MPM stages 4 and 5, even though diagnostic accuracy was above 90.8% even for stages 1 and 3 (Table 5). In spite of the weighted kappa coefficients denoting an almost perfect agreement, diagnostic accuracy in the identification of MPM stage 2 was only about 83% in both sessions. Of note, when dealing with diagnostic agreement of a staging method having several clusters (i.e. 5 MPM stages) sensitivity (when an equal number of stages are investigated) and PPV should be considered. These two parameters quantify the capability of a rater in the identification of any MPM stage, irrespective of the number of true negative cases belonging to the other stages. In the present study, sensitivity and PPVs were generally high for all the stages with lowest scores for stage 2, where the scores were 58.8% and 59.3% for sensitivity and PPV, respectively. The MPM stages 1 and 3 showed greater scores as compared to those for stage 2, even though lower as compared to those for stages 4 and 5 (Table 5). This evidenced the MPM stage 2 as the most critical in terms of diagnostic accuracy (and repeatability), and reinforces the concept that studies on stage-based radiographic growth indicators have to analyze specifically repeatability of each stage.[20]

A possible explanation for the results regarding MPM stage 2, and partially stages 1 and 3, would reside in the procedure followed for the inclusion of the radiographs. Indeed, most of the radiographs selected had stages 1 year apart with the corresponding previous or subsequent stage (Table 1). For instance, the MPM stage 1 radiographs were chosen only when the subsequent year an MPM stage 2 could be clearly recognized. This implied that several 'borderline' cases were included making the staging more difficult. Moreover, the

present study made use of hand-and-wrist radiographs taken decades ago, while the use of contemporary radiographs taken by digital instruments may give more detailed images and a consequent easier staging. A further possible explanation may relate to the concept that raters did not have major experience in the use of the method, and none underwent specific training with an expert assessor. Instead, each rater was given written instructions (along with a diagram, Figure 1), according to a research design previously reported for the CVM method. [21] As descriptive pictures are usually only a simplified version of the full range of possibilities, proper training may have increased skills in staging and hence repeatability of the method. In this regard, repeatability of the CVM method has been reported poor [19,21] or satisfactory [20] for non-trained and trained raters, respectively (irrespective of previous experience in orthodontics).[22] Nonetheless, the overall percentage of agreements (Table 3) and overall weighted kappa coefficients (Table 4) reported herein for non-trained raters are greater than those reported for trained raters in the CVM staging.[20]

Clinical implications

Overall repeatability and diagnostic agreement of the 5-stage MPM method is satisfactory although not full, with MPM stage 2 being the most critical. According to previous evidence, MPM stage 2 is usually preceding the mandibular growth peak (which would be concomitant with stage 3), therefore, the correct identification of this stage has major clinical implications when dealing with orthopedic treatment, i.e. skeletal Class II malocclusion.[12,23] However, the limited radiation exposure would allow longitudinal recordings from which a more reliable staging can be obtained. Taking into account the hand-and-wrist maturation method proposed by Fishman, [3] although not investigated herein, a combined evaluation with the maturation of the distal phalanx of the third finger may also be useful in case of doubtful staging. Considering the present evidence, along with previous indications for the use of ossification events instead of single stages [24] because of the unpredictable duration of every stage,[13] it would be advisable to follow the maturational process of the third finger middle phalanx over time to identify reliably proper treatment timing in individual subjects.

CONCLUSIONS

- Overall, the MPM method has a satisfactory level of repeatability and diagnostic agreement.
- About 1 case out of 5 remains misclassified, disagreement is mostly limited to 1-stage-apart, with stage 2 being the most critical.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

AKWOLEDGEMNTS

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Table 5. *Diagnostic accuracy parameters for each third finger middle phalanx maturation stage according to the sessions (T1 and T2) for the whole group of raters.*
PPV, positive predictive value, NPV, negative predictive value. n=16 for each MPM stage.

MPM stage	Parameter	With reference standard	
		T1 mean (95 %CI)	T2 mean (95 %CI)
1	Sensitivity	72.5% (51.0-94.0)	68.2% (46.2-90.1)
	Specificity	96.1% (91.4-100)	96.4% (91.9-100)
	PPV	83.5% (65.1-100)	83.0% (62.6-100)
	NPV	93.4% (87.4-99.3)	92.5% (86.2-98.7)
	Accuracy	91.4% (85.3-97.5)	90.8% (84.4-97.1)
2	Sensitivity	58.8% (35.9-81.6)	62.5% (39.2-85.8)
	Specificity	89.8% (82.5-97.2)	89.1% (81.4-96.7)
	PPV	58.9% (33.9-83.9)	59.3% (35.9-82.8)
	NPV	89.9% (82.6-97.2)	90.5% (83.3-97.7)
	Accuracy	83.7% (75.6-91.7)	83.8% (75.7-91.8)
3	Sensitivity	85.0% (68.5-100)	81.9% (64.2-99.5)
	Specificity	92.2% (85.6-98.8)	92.7% (86.3-99.0)
	PPV	73.9% (53.9-93.9)	74.4% (54.0-94.8)
	NPV	96.2% (91.6-100)	95.5% (90.5-100)
	Accuracy	90.8% (84.5-97.1)	90.5% (84.1-97.0)
4	Sensitivity	91.2% (78.1-100)	91.3% (78.1-100)
	Specificity	99.4% (97.7-100)	98.5% (95.6-100)
	PPV	98.0% (91.9-100)	94.9% (85.0-100)
	NPV	97.9% (94.4-100)	97.9% (94.4-100)
	Accuracy	97.8% (94.6-100)	97.1% (93.5-100)
5	Sensitivity	100%	98.6% (93.4-100)
	Specificity	99.1% (96.9-100)	98.8% (96.3-100)
	PPV	97.1% (89.9-100)	96.1% (87.8-100)
	NPV	100%	99.5% (98.2-100)
	Accuracy	99.3% (97.5-100)	98.9% (97.1-100)

REFERENCES

1. Baccetti T, Franchi L, McNamara JA, Jr. The cervical vertebral maturation (CVM) method for the assessment of optimal treatment timing in dentofacial orthopedics. Semin Orthod 2005;11:119-29.
2. Petrovic A, Stutzmann J, Lavergne J. Mechanism of craniofacial growth and modus operandi of functional appliances: a cell-level and cybernetic approach to orthodontic decision making. In: Carlson DS, editor. Craniofacial growth theory and orthodontic treatment. Monograph 23. Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, University of Michigan; 1990. p. 13-74.
3. Fishman LS. Radiographic evaluation of skeletal maturation. A clinically oriented method based on hand-wrist films. Angle Orthod. 1982;52:88-112.
4. Greulich WW, Pyle SI. Radiographic atlas of skeletal development of the hand and wrist. 2nd edition ed. Stanford, CA: Stanford University Press; 1959.
5. Hassel B, Farman AG. Skeletal maturation evaluation using cervical vertebrae. Am J Orthod Dentofacial Orthop. 1995;107:58-66.
6. Perinetti G, Baccetti T, Contardo L, Di Lenarda R. Gingival crevicular fluid alkaline phosphatase activity as a non-invasive biomarker of skeletal maturation. Orthod Craniofac Res. 2011;14:44-50.
7. Baccetti T, Franchi L, McNamara JA, Jr. An improved version of the cervical vertebral maturation (CVM) method for the assessment of mandibular growth. Angle Orthod. 2002;72:316-23.
8. Perinetti G, Primozic J, Sharma B, Cioffi I, Contardo L. Cervical vertebral maturation method and mandibular growth peak: a longitudinal study of diagnostic reliability. Eur J Orthod. 2018;40:666-72.
9. Perinetti G, Bianchet A, Franchi L, Contardo L. Cervical vertebral maturation: An objective and transparent code staging system applied to a 6-year longitudinal investigation. Am J Orthod Dentofacial Orthop. 2017;151:898-906.
10. Ball G, Woodside D, Tompson B, Hunter WS, Posluns J. Relationship between cervical vertebral maturation and mandibular growth. Am J Orthod Dentofacial Orthop. 2011;139:e455-61.
11. Perinetti G, Braga C, Contardo L, Primozic J. Cervical vertebral maturation: Are post-pubertal stages attained in all subjects? Am J Orthod Dentofacial Orthop. 2020;157:305-12.
12. Perinetti G, Contardo L. Reliability of growth indicators and efficiency of functional treatment for skeletal Class II malocclusion: Current evidence and controversies. Biomed Res Int. 2017;2017:1367691.
13. Perinetti G, Sbardella V, Contardo L. Diagnostic reliability of the third finger middle phalanx maturation (MPM) method in the identification of the mandibular growth peak. Eur J Orthod. 2017;39:194-201.
14. Perinetti G. The third finger middle phalanx maturation (MPM) method to assess timing of functional treatment for skeletal class II malocclusion: Report of three cases. Case Rep Dent. 2019;2019:8382612.
15. De Stefani A, Bruno G, Siviero L, Crivellin G, Mazzoleni S, Gracco A. Middle phalanx maturation of the third finger (MPM) method in the evaluation of skeletal age in a growing orthodontic patient. Int Orthod. 2018;16:499-513.
16. Brenner H, Kliebsch U. Dependence of weighted kappa coefficients on the number of categories. Epidemiology. 1996;7:199-202.
17. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977;33:159-74.
18. Greenhalgh T. How to read a paper. Papers that report diagnostic or screening tests. BMJ. 1997;315:540-3.
19. Nestman TS, Marshall SD, Qian F, Holton N, Franciscus RG, Southard TE. Cervical vertebrae maturation method morphologic criteria: Poor reproducibility. Am J Orthod Dentofacial Orthop. 2011;140:182-8.
20. Perinetti G, Caprioglio A, Contardo L. Visual assessment of the cervical vertebral maturation stages: A study of diagnostic accuracy and repeatability. Angle Orthod. 2014;84:951-6.
21. Gabriel DB, Southard KA, Qian F, Marshall SD, Franciscus RG, Southard TE. Cervical vertebrae maturation method: poor reproducibility. Am J Orthod Dentofacial Orthop. 2009;136:478 e1-7.
22. Rongo R, Valleta R, Bucci R, Bonetti GA, Michelotti A, D'Anto V. Does clinical experience affect the reproducibility of cervical vertebrae maturation method? Angle Orthod. 2015;85:841-7.
23. Perinetti G, Primozic J, Franchi L, Contardo L. Treatment effects of removable functional appliances in pre-pubertal and pubertal Class II patients: A systematic review and meta-analysis of controlled studies. PLoS One. 2015;10:1-35 e0141198.
24. Houston WJ. Relationships between skeletal maturity estimated from hand-wrist radiographs and the timing of the adolescent growth spurt. Eur J Orthod. 1980;2:81-93.