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Maturation of the middle phalanx of the third finger and cervical vertebrae: a comparative and diagnostic agreement study

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Structured Abstract

Objective – Diagnostic agreement on individual basis between the third middle phalanx maturation (MPM) method and the cervical vertebral maturation (CVM) method has conjecturally been based mainly on overall correlation analyses. Herein, the true agreement between methods according to stage and sex has been evaluated through a comprehensive diagnostic performance analysis.

Subjects and methods – Four hundred and fifty-one Caucasian subjects were included in the study, 231 females and 220 males (mean age, 12.2 ± 2.5 years; range, 7.0–17.9 years). The X-rays of the middle phalanx of the third finger and the lateral cephalograms were examined for staging by blinded operators, blinded for MPM stages and subjects' age. The MPM and CVM methods based on six stages, two pre-pubertal (1 and 2), two pubertal (3 and 4), and two post-pubertal (5 and 6), were considered. Specifically, for each MPM stage, the diagnostic performance in the identification of the corresponding CVM stage was described by Bayesian statistics.

Results – For both sexes, overall agreement was 77.6%. Most of the disagreement was due to 1 stage apart. Slight disagreement was seen for the stages 5 and 6, where the third middle phalanx shows an earlier maturation.

Conclusions – The two maturational methods show an overall satisfactorily diagnostic agreement. However, at post-pubertal stages, the middle phalanx of the third finger appears to mature earlier than the cervical vertebrae. Post-pubertal growth phase should thus be based on the presence of stage 6 in MPM.

Key words: cervical vertebrae; diagnosis; finger phalanges; growth

Introduction

When dealing with skeletal disharmonies for treatment efficiency reasons, the precise identification of skeletal maturity, that is, the growth phase, with particular regard to the onset of the pubertal growth spurt, is required (1, 2). Several indices have been proposed to identify the skeletal maturation phases (1–6). The most commonly used are the radiography-based, hand-wrist maturation [for review, see (7)] and cervical vertebral maturation (CVM) [for review, see (1)] methods.

Several studies have previously evaluated the relationship between these two methods [for review, see (8)] generally reporting a high degree of correlation. However, all of these previous studies were hampered by the use of a specific CVM recording (9) not consistent with the described methods (1, 10) validated in clinical trials (11) or by lack of an analysis of diagnostic agreement in individual subjects (8, 12). Indeed, a high correlation coefficient does not necessarily prove a diagnostic agreement in individual subjects, as was recently showed for dental maturation (13). This issue may be addressed by a dedicated diagnostic performance analysis that is, however, still missing. Moreover, very few studies (14–16) have specifically been focused on the correlations between the middle phalanx maturation (MPM) of the third finger and the CVM method. The results of these investigations were further limited by the lack of an accurate recording of the repeatability of the measurements of both maturational methods (14), or because only male subjects were included (15).

This study was designed to address the following issues: 1) Does the middle phalanx of the third finger and cervical vertebral maturations have satisfactorily diagnostic agreement? and 2) If disagreement is seen, how is this structured among the different stages or sexes? This study ultimately verified whether the MPM method, as proposed herein, may be proposed as a valid indicator of growth phase in individual subjects.

Materials and methods

Study population and design

The databases between January 2008 and August 2013 of the Sections of Stomatology of the Department of Medical, Surgical and Health Sciences, University of Trieste, and of the Department of Oral Sciences, Second University of Naples, were screened. This study included subjects who were seeking orthodontic treatment. Signed informed consent was obtained from the parents of the subjects prior to study entrance, and the protocol was reviewed and approved by the local ethical committee. In particular, an X-ray of the middle phalanx of the middle finger and a lateral cephalogram is taken as part of the routine clinical recording. The following inclusion criteria were applied: 1) age between 7 and 18 years; 2) absence of anomalies of either the fingers or the vertebrae; 3) good general health with the absence of any nutritional problems; 4) no history of trauma at the cervical region or right hand; and 5) Caucasian ethnicity. A total of 451 subjects (231 females and 220 males) were included in the study (mean age, 12.2 ± 2.5 years; range, 7.0–17.9 years). In a *posteriori* power analysis, sample size of 278 subjects is enough to detect an agreement between the maturational methods as low as 30% considering a relative error (the difference between the estimated and true reliability), as low as 20% with a power of 0.8, and an alpha set at 0.05 (17).

Radiographic recordings

The radiographic recording of the middle phalanx of the middle finger was performed as previously reported (18). Briefly, the patients were instructed to place their right hand with the palm downward on a flat table and with the third finger straight and centered on a standard 3×4 cm periapical sensor (Dürr Dental, Bietigheim-Bissingen, Germany). The cone of the dental X-ray machine (Kodak 2200 intraoral x-ray system; Eastman Kodak Company, Rochester, NY, USA) was positioned in light contact with

the middle phalanx and perpendicular to the dental X-ray sensor. Settings were of 70 kV and 7 mA with an exposure time of 0.097 s. An automatic developer (VistaScan PERIO; Dürr Dental) was used for film processing. A dedicated X-ray machine (KODAK 8000C; Eastman Kodak Company) was employed for the recording of lateral head cephalogram. Settings were of 73–77 kV, 12 mA, with an exposure time of 0.80 s. Radiographs of low quality were excluded.

Middle phalanx maturation (MPM) method

The MPM method as proposed herein comprises 6 stages [middle phalanx stages, (MPS)], as shown in Fig. 1. Definitions of the stages were based on previous descriptions by Fishman (3), Hägg and Taranger (5), and Rajagopal and Kansal (14), with modifications:

MPS1

When the epiphysis is narrower than the metaphysis, or when the epiphysis is as wide as metaphysis (5), but with both tapered and rounded lateral borders (14) (Fig. 1, MPS1b). Epiphysis and metaphysis are not fused. This stage was earlier reported as MP3-F and described to be attained more than 1 year before the onset of the pubertal growth spurt (5).

MPS2

When the epiphysis is at least as wide as the metaphysis (5) with sides increasing thickness and showing a clear line of demarcation at right angle (5). In case of asymmetry between the two sides, that is, one typical of MPS2 and the other less mature, the former is used to assign the stage. This stage was earlier reported as SMI2 (3) or as MP3-FG described to be attained 1 year before the onset of the pubertal growth spurt (5).

MPS3

When the epiphysis is either as wide as or wider than the metaphysis (5) with lateral sides showing an initial capping toward the metaphysis (5). In case of asymmetry between the two sides, for example, one typical of MPS3 and the other less mature, the former is used to assign the stage. Epiphysis and metaphysis are not fused. This stage was earlier reported as SMI6 (3) or as MP3-G, both described to be attained at coincidence of the pubertal growth spurt (5).

MPS4

When the epiphysis begins to fuse with the metaphysis (5) although contour of the former is still clearly recognizable. Both sides of the epiphysis form obtuse angle to distal border,

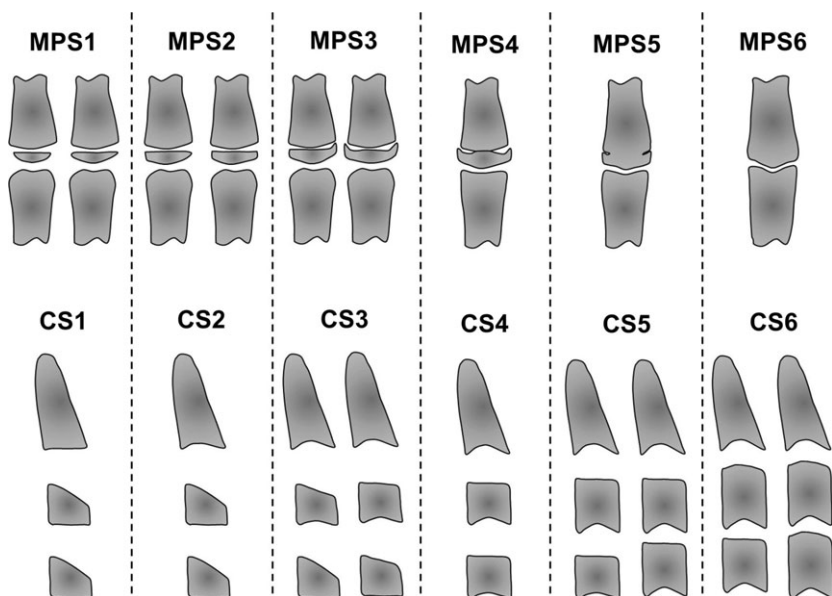


Fig. 1. The third middle phalanx (upper) and cervical vertebral (lower) maturational stages. MPS, third middle phalanx maturational stage; CS, cervical vertebral maturational stage.

and the capping is still clearly detectable. This stage was earlier reported as MP3-H and described to be attained after the pubertal growth spurt, that is, during the deceleration of the curve of growth (5).

MPS5

When the epiphysis is mostly, but not completely fused with the metaphysis (5), and the distal contour of the former begins to be less clearly recognizable. This specific stage was initially proposed by Rajagopal and Kansal (14) and reported as MP3-HI and was reported to be attained toward the end of the pubertal growth spurt (14).

MPS6

When the epiphysis totally fused with the metaphysis (5), and the distal contour of the former is not recognizable. This stage was earlier reported as SMI10 (3) or as MP3-I, both described to be attained at the end of the pubertal growth spurt (5).

An experienced orthodontist (GP), who was blinded to the CVM stages, assessed the MPM stages.

Cervical vertebral maturation method

The CVM method as initially proposed by Hassel and Farman (10), and subsequently modified according to Baccetti et al. (1), comprises 6 stages (CS) as shown in Fig. 1 and as briefly defined as follows:

CS1

When the lower borders of the second, third, and fourth vertebrae (C2, C3, and C4) are flat, and the bodies of C3 and C4 are trapezoid in shape. This stage has been reported to be attained at least 2 years before the pubertal growth spurt.

CS2

When only the lower border of C2 is concave, and the bodies of C3 and C4 are trapezoid. This stage has been reported to be attained 1 year before the growth spurt.

CS3

When the lower borders of both C2 and C3 have concavities, and the bodies of C3 and C4 are either trapezoid or rectangular horizontal in shape. This stage has been reported to occur in coincidence with the onset of the pubertal growth spurt, that is, acceleration curve of growth.

CS4

When the lower borders of C2–C4 have concavities, and the bodies of both C3 and C4 are rectangular horizontal. This stage has been described to be attained at coincidence of the pubertal growth spurt, but after the peak height velocity, that is, during the deceleration curve of growth.

CS5

When the lower borders of C2–C4 have concavities, and at least one or both of the bodies of C3 and C4 is square. This stage has been reported to occur 1 year after the growth spurt.

CS6

When the lower borders of C2–C4 have concavities, and at least one or both of C3 and C4 are rectangular vertical. This stage has been reported to occur at least 2 years after the growth spurt.

The lateral cephalograms were cropped to include C2–C4 and to eliminate any additional information, such as stage of dentition that might have biased the staging. An experienced orthodontist (LC) with 5-year experience in the CVM method including training with the developers of this staging, blinded to the MPM stages and subjects' age, assessed the CVM stages.

Statistical analysis

All these analyses were performed for each sex separately as well as for the whole sample. Mean ages of the subjects, clustered according to each stage of either maturational methods, have been plotted, and within each MPM stage, the prevalence of the CVM stages was calculated. To determine the degree of correlation between the two maturational indices, the Spearman rank correlation coefficient was used. The diagnostic agree-

ment between the MPM and CVM methods was assessed by a linearly weighted κ coefficient (19).

Moreover, a dedicated diagnostic performance analysis, that is, Bayesian statistics, was also performed to establish the diagnostic performance of each MPM stage for the identification of each corresponding CVM stage. This analysis included sensitivity, specificity, positive and negative predictive values, accuracy, and positive likelihood ratio (LHR) (20). A threshold of a positive LHR of ≥ 10 (21) was considered for assessment of satisfactory reliability of any MPM stage for the identification of any of the CVM stages, that is, satisfactory diagnostic agreement.

The percentage agreement and weighted κ statistics were calculated for evaluation of the intra-examiner agreement. For appraisal of the stages of MPM and CVM, the intrarater weighted κ coefficients calculated on 30 pairs of recordings randomly selected were >0.92 .

SPSS software 13.0 (SPSS® Inc., Chicago, IL, USA), MedCalc® software 12.3.3.0 (MedCalc Software, Mariakerke, Belgium) and the interactive Stats Calculator (<http://kclearinghouse.ca/cebm/toolbox/statscalc>) were used to perform the statistical analyses. A p value < 0.05 was considered as significant.

Results

The comparative mean ages of the subjects for each MPM or CVM stage according to the sexes are shown in Fig. 2. Mean ages were very similar with few exceptions for males at stage 5, in which the differences were about 0.6 years. For both the maturational methods, the differences in chronological ages between two consecutive stages from 2 to 5 ranged from about 0.6 to 1.5 years for both sexes. Irrespective of the maturational method, females attained stages 2–6 generally 1 year earlier than males. Clinical examples for each MPM and CVM stages are shown in Fig. 3.

Of the whole sample, 350 subjects (77.6%) showed a full agreement between the two maturational stages, 89 subjects (19.7%) showed a one-stage-apart disagreement, while in only 12 cases (2.7%), a two-stage-apart disagreement

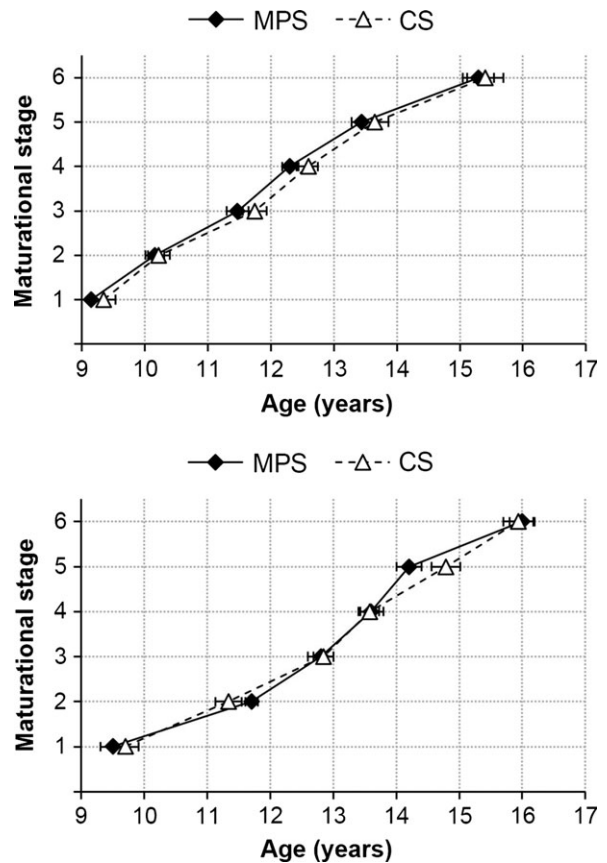


Fig. 2. Chronological ages among the different third finger middle phalanx and cervical vertebral maturational stages for females (upper) and males (lower). Data are presented as mean \pm standard error of the mean. MPS, third middle phalanx maturational stage; CS, cervical vertebral maturational stage. Females, $n = 231$; males, $n = 220$.

was seen. The total agreements were 77.9 and 77.3% for females and males, respectively. The correlation coefficient between the two maturational methods was 0.953 ($p < 0.001$) for the whole sample, and of 0.953 ($p < 0.001$) and 0.952 ($p < 0.001$) for females and males, respectively. The weighted κ coefficient (95% CI) for the diagnostic agreement among the different MPM and CVM stages was 0.88 (0.85–0.90) for the whole sample, and of 0.88 (0.84–0.91) and 0.87 (0.84–0.91) for females and males, respectively.

Detailed relative distributions of the different MPM stages according to CVM stages for females and males are summarized in Table 1. The percentage of exact agreement of the MPM stages with the corresponding CVM stages ranged between 68.3% (MPS2/CS2) and 97.6% (MPS1/CS1) for females, and between 57.7% (MPS5/CS5) and 90.6% (MPS1/CS1) for males.

Fig. 3. Clinical examples from six subjects of this study for the third middle phalanx and cervical vertebral maturational stages. MPS, third middle phalanx maturational stage; CS, cervical vertebral maturational stage. Note that pubertal middle phalanx maturation stages 3 and 4 may or may not show undulation of the border of the metaphysis.

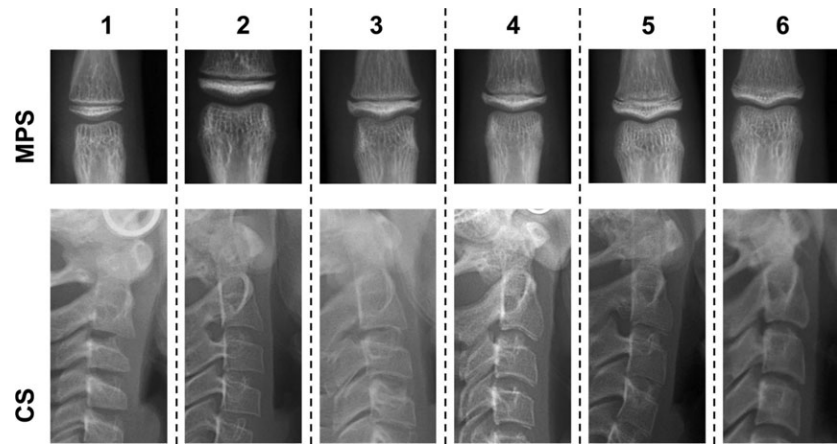


Table 1. Relative distributions of the different third middle phalanx maturational stages according to cervical vertebral maturational stages for females and males

Sex	Third finger middle phalanx maturational stage	Cervical vertebral maturational stage						Total
		CS1	CS2	CS3	CS4	CS5	CS6	
Females	MPS1	97.6% (41)	2.4% (1)	–	–	–	–	42
	MPS2	24.4% (10)	68.3% (28)	4.9% (2)	2.4% (1)	–	–	41
	MPS3	3.1% (1)	15.6% (5)	75.0% (24)	6.3% (2)	–	–	32
	MPS4	–	–	13.5% (5)	78.4% (29)	8.1% (3)	–	37
	MPS5	–	–	5.1% (2)	15.4% (6)	76.9% (30)	2.6% (1)	39
	MPS6	–	–	–	5.0% (2)	25.0% (10)	70.0% (28)	40
Males	MPS1	90.6% (58)	21.1% (6)	–	–	–	–	64
	MPS2	21.1% (8)	73.7% (28)	5.3% (2)	–	–	–	38
	MPS3	–	6.5% (2)	77.4% (24)	16.1% (5)	–	–	31
	MPS4	–	–	7.1% (2)	75.0% (21)	10.7% (3)	7.1% (2)	28
	MPS5	–	–	7.7% (2)	26.9% (7)	57.7% (15)	7.7% (2)	26
	MPS6	–	–	–	6.1% (2)	21.2% (7)	72.7% (24)	33

MPS, third middle phalanx maturational stage; CS, cervical vertebral maturational stage.

Data are presented as percentage (n) cases of each MPS within each CS. –, no cases. Females, n = 231; males, n = 220.

The other diagnostic performance parameters of different MPM stages and the corresponding CVM stages are summarized in Table 2. Sensitivity ranged between 72.5% (MPS4/CS4) and 96.6% (MPS6/CS6) for females, and between 60.0% (MPS4/CS4 and MPS5/CS5) and 87.9% (MPS1/CS1) for males. Specificity values were all above 90% for females and males.

Positive predictive values ranged between 68.3% (MPS2/CS2) and 97.6% (MPS1/CS1) for females, and between 57.7% (MPS5/CS5) and 90.6% (MPS1/CS1) for males. Negative predictive values and the accuracy values were all above

90% for both the sexes. Finally, positive LHRs ranged between 12.5 (MPS2/CS2) and 131.3 (MPS1/CS1) for females, and between 10.7 (MPS5/CS5) and 22.5% (MPS1/CS1) for males.

Discussion

The present study reported on the diagnostic agreement between the different stages of maturation of the middle phalanx of the third finger and the cervical vertebral on a population of Caucasian growing subjects.

Table 2. Overall diagnostic performance of each third finger middle phalanx maturation stages for identification of corresponding the cervical vertebral maturational stages for females and males

Sex	Third finger middle phalanx maturational stage	Diagnostic parameter					
		Sensitivity	Specificity	Positive predictive value	Negative predictive value	Accuracy	Positive LHR
Females	MPS1	78.8 (64.3–88.5)	99.4 (96.8–99.9)	97.6 (87.6–99.6)	94.2 (89.9–96.7)	94.8 (91–97)	131.3 (19.8–869.9)
	MPS2	82.4 (66.5–91.7)	93.4 (89–96.1)	68.3 (53–80.4)	96.8 (93.2–98.5)	91.8 (87.3–94.8)	12.5 (7.2–21.6)
	MPS3	72.7 (55.8–84.9)	96 (92.3–98)	75 (57.9–86.7)	95.5 (91.7–97.6)	92.6 (88.3–95.4)	18.2 (8.9–37.2)
	MPS4	72.5 (57.2–83.9)	95.8 (91.9–97.9)	78.4 (62.8–88.6)	94.3 (90.1–96.8)	91.8 (87.3–94.8)	17.3 (8.6–35)
	MPS5	69.8 (54.9–81.4)	95.2 (91.1–97.5)	76.9 (61.6–87.3)	93.2 (88.7–96)	90.5 (85.8–93.8)	14.5 (7.4–28.2)
	MPS6	96.6 (82.9–99.4)	94.1 (90–96.6)	70.0 (54.6–81.9)	99.5 (97.1–99.9)	94.4 (90.5–96.8)	16.4 (9.4–28.6)
Males	MPS1	87.9 (77.7–93.8)	96.1 (91.8–98.2)	90.6 (81–95.6)	94.9 (90.2–97.4)	93.6 (89.4–96.2)	22.5 (10.2–49.5)
	MPS2	77.8 (61.9–88.3)	94.6 (90.3–97.0)	73.7 (58.0–85.0)	95.6 (91.6–97.8)	91.8 (87.2–94.8)	14.4 (7.7–27)
	MPS3	80.0 (62.7–90.5)	96.3 (92.6–98.2)	77.4 (60.2–88.6)	96.8 (93.2–98.5)	94.1 (90.0–96.6)	21.6 (10.2–45.6)
	MPS4	60.0 (43.6–74.4)	96.2 (92.4–98.1)	75.0 (56.6–87.3)	92.7 (88.1–95.6)	90.5 (85.6–93.8)	15.8 (7.3–34.3)
	MPS5	60.0 (40.7–76.6)	94.4 (90.2–96.9)	57.7 (39.0–74.5)	94.8 (90.7–97.1)	90.5 (85.6–93.8)	10.7 (5.5–20.7)
	MPS6	85.7 (68.5–94.3)	95.3 (91.3–97.5)	72.7 (55.8–84.9)	97.9 (94.7–99.2)	94.1 (90.0–96.6)	18.2 (9.5–35)

MPS, third middle phalanx maturational stage; LHR, likelihood ratio. Data are presented as mean (95% confidence interval). Females, n = 231; males, n = 220.

The CVM method has been correlated with both the statural and the mandibular growth spurt (22, 23), and even with levels of biomarkers of growth (24, 25). A randomized clinical trial on functional treatments has proved the validity of this method in terms of skeletal outcome (11). Of note, previous studies reported a low to good reproducibility of the CVM method with weighted κ values ranging from 0.36 to 0.79 according to the different raters (26). A later investigation, using the same sample and raters, reported that the assignment of the shape of the bodies of C3 and C4 is the least reproducible part of the CVM staging (27). In spite of this evidence, the intrarater reproducibility obtained in the present study was satisfactory with weighted κ of 0.92. The high reproducibility seen herein was likely due to the extensive training of the rater.

In addition to specific training, the CVM method also requires a lateral head film, which is available as a pre-treatment record. However, in several instances, optimal treatment timing is to be delayed until after the diagnosis, making necessary a later re-evaluation of the growth phase. Moreover, the cervical vertebrae might be partially covered by the protection collar, which would be necessary to reduce radiation exposure (28). Even though the radiographical recording of the hand and wrist has been shown to be safer in terms of radiation exposure (28), this method requires anyway additional X-ray exposure of a hand and wrist as a whole, other than a dedicated X-ray machine. Besides, re-execution of either a lateral head cephalogram or a hand-and-wrist film for a re-evaluation of growth phases is not indicated according to the most recent guidelines (29).

In the present study, the mean chronological ages at which both females and males reached the pubertal growth spurt, as recorded by the MPS3 or CS3 (Fig. 2), are comparable with previously reported data (3, 5, 30).

The correlation coefficient seen in the present study between the MPM and CVM methods is very similar to that above 0.94 obtained in a previous investigation (16) that was based on the maturation staging of the middle phalanx of the third finger proposed by Hägg and Taranger (5).

Moreover, the weighted κ coefficients retrieved herein were very high up to 0.88 denoting a very good overall agreement between the two maturational methods. Again, this analysis was missed in the previous studies (14–16).

In the present study, about 78% of agreement was found, and disagreements showed mostly a single stage apart. The disagreement seen herein may be explained by the fine transitional morphological changes in either third middle phalanx or cervical vertebrae. However, good agreements between the maturational methods were those for stages 3, in which all the diagnostic parameters showed a high performance of the MPM method in the identification of the corresponding CVM staging (Table 2). Therefore, events responsible for the onset of the pubertal growth spurt, that is, hormonal changes (25), would induce concomitant morphological changes in both the third middle phalanx and cervical vertebrae.

Satisfactory diagnostic agreement with accuracy and positive LHRs values above 90% and 10%, respectively, for each MPM stage in the identification of the corresponding CVM stage (Table 2). However, the calculation of the accuracy and the positive LHRs takes into account both the identification of true positive and true negative cases. Therefore, when dealing with several possible clustering, an important diagnostic parameter is the positive predictive value that gives an indication of the capability of a given MPM stage in the identification of the corresponding CVM stage, irrespective of the number of true negative cases belonging to the other stages. By analyzing the positive predictive values, in combination with the frequency distributions of the maturational staging, a general tendency for the MPM to reach the stage 6 slightly earlier than the CVM is evident (Table 2). The concept that small morphological changes at the third middle phalanx may be better detected than those at the cervical vertebrae may also be responsible for this evidence. Therefore, from a clinical perspective, a safe diagnosis of the attainment of the post-pubertal growth phase especially in males should rely on the attainment of MPS6, rather than MPS5.

Further studies on the correlation/diagnostic performance of the present MPM method with statural or mandibular growth, or even to other hand-wrist maturation methods, are warranted.

Clinical implications

The availability of a radiographical method based on a very minimal radiation exposure appears to be a valuable tool in clinical practice. The MPM method appears to be a valid indicator of the onset of the pubertal growth spurt in individual subjects and may therefore find wide applications for planning treatment timing for functional treatments for skeletal class II or III (1) and constricted maxilla (31). Finally, the MPM method is of easy execution and interpretation and may be performed in any clinical setting with minimal instrumentation. This method may also be complementary when the CVM staging would be uncertain or not derivable from a lateral cephalogram.

Conclusions

1) The MPM and CVM methods show an overall satisfactorily diagnostic agreement; 2) good agreement for stages 3 that corresponds to the onset of the pubertal growth spurt; and 3) a slight disagreement at stage 5, in which the third

middle phalanx appears to mature earlier than the cervical vertebrae.

Clinical relevance

Individual monitoring of the growth phase, with particular regard to the onset of the pubertal growth spurt, has been advocated to obtain predictable treatment effects when dealing with skeletal malocclusions. Although slight differences exist, when compared with the cervical vertebral method, the maturational staging of the middle phalanx of the third finger appears to be a valid indicator of the onset and of the end of the pubertal growth spurt in individual subjects. When a lateral head film is not available or not clear in the cervical area, the middle phalanx maturation method may be used as a valid alternative method.

Competing interest

The authors declare that they have no competing financial interests.

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