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Duration of stages of the Middle Phalanx Maturation method in a contemporary population: A 6-year longitudinal analysis

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Abstract

Objective: To determine the duration and age at the beginning of each stage corresponding to the circumpubertal period in the Middle Phalanx Maturation method (MPM) and to assess the differences between males and females.

Materials and Methods: Sets of X-rays of the middle phalanx of the third finger taken at 6-month intervals were analysed for 246 skeletal Class I subjects (102 females and 144 males) between 9 and 15 years of age. After staging, the duration of each stage was derived from chronological ages, and the difference between males and females for both duration and age at the beginning of each stage was investigated.

Results: The median duration for MPS2 and MPS3 was 1 year for both sexes, while MPS4 showed a median duration of 1 year in females and 9 months in males, with no significant differences between the sexes. Mean age at the beginning of MPS2 was 10y11m for females and 11y11m for males; for MPS3, it was 11y8m for females and 13y1m for males; for MPS4, it was 12y9m for females and 13y11m for males; for MPS5, it was 13y4m for females and 14y3m for males. The differences between the sexes were statistically significant for all the stages ($P < .001$).

Conclusions: This study confirms, with relevant sample size, the median duration of 1 year for each MPM stage from MPS2 to MPS4. Despite the distinctive interindividual variability, the interquartile range is 6 months or less for all but one interval, confirming the soundness of the results.

KEYWORDS
growth, Middle Phalanx Maturation, orthodontics, skeletal age

1 | INTRODUCTION

Evaluation of skeletal growth is a fundamental step for the functional treatment of skeletal malocclusions, particularly skeletal Class II malocclusions.[1,2] Regardless of the type of orthodontic appliance used (fixed or removable), orthopaedic treatment has better skeletal results if performed during the pubertal growth spurt of the patient.[1–3] In recent decades, many growth indicators have been proposed. The Middle Phalanx Maturation method has raised interest because of the reduced X-ray exposure compared to other radiographic methods and because of its easy interpretation of stages and absence of superimposition of anatomical structures. This method has good diagnostic accuracy and predictive values, with a likelihood ratio of 10.3 for stage MPS2 for the identification of imminent

mandibular growth peak.[4] Furthermore, previous studies showed good intra-operator repeatability when staging is performed by a trained orthodontist.[4] The advantages of this method compared to CVM are not only a superior diagnostic accuracy but also a reduced X-ray exposure and, as such, the possibility of long-term longitudinal monitoring.

To date, most studies on the MPM method have a cross-sectional design, and the MPM method is analysed in correlation with the Cervical Vertebral Maturation method.[5–8] But despite the extensive use and presence in the literature of the CVM, recent studies questioned its absolute validity.[9–11] In particular, one study highlighted an insufficient diagnostic accuracy of stages CS2, CS3 and CS4 (0.70, 0.76 and 0.77, respectively). These low values seem to be mainly ascribable to the presence of many false positives.[9] As such, new research is needed to analyse the chronology of the MPM stages independently from other methods.

To be able to intercept accurately and without fail the correct timing for the beginning of treatment, essential information is the duration of the single stages corresponding to the circumpubertal period. In this way, it is possible to know when closer monitoring is necessary and when we are confidently approaching the mandibular growth peak. The identification of the duration of stages has been already investigated for the HWM method,[12,13] the CVM method[14,15] and the MPM method.[4] In particular, a 2017 study by Perinetti et al gives some indications on the supposed duration of stages MPS2 and MPS3, placing it around 1 year.[12] However, since this was not the main objective of the study, the sample analysed was quite scarce (25 and 21 subjects for MPS2 and MPS3, respectively), and no meaningful comparison could be made between the sexes. As such, a new investigation on the duration of stages MPS2, MPS3 and MPS4 with a larger sample size and without correlations with the CVM method is needed to fill this literature gap. Furthermore, the above-mentioned study analysed files from the Burlington and Oregon Growth Studies that can be heavily influenced by secular trends.[16,17]

This study aims to fill the literature gap through a 6-year longitudinal analysis of diagnostic records from a contemporary population of orthodontic patients. The goal is to understand the duration of each stage from MPS2 to MPS4 and to verify whether there is a difference between the sexes. Secondarily, we aim to compare the age at the beginning of each stage from MPS2 to MPS5 between males and females. The long-term goal is to understand the best monitoring interval for the identification of the skeletal growth peak. The null hypothesis is that there is no difference between the duration of the circumpubertal stages of the MPM method and sex.

2 | MATERIALS AND METHODS

The study is retrospective and was approved by the Ethics Committee of the University of Trieste (Protocol code n. 115, date of approval 24 June 2021). Informed consent for publication was obtained from all subjects involved in the study. The sample was collected from the orthodontic database of the Section of Orthodontics of the Department of Medicine, Surgery and Health Sciences, University of Trieste. The database was screened from January 2016 to August 2022. Inclusion criteria were (i) the presence of an X-ray of the right hand third phalanx of the middle finger at the time of the orthodontic check-up (T_0), (ii) the presence of at least one other X-ray of the middle finger taken at 6-month intervals, (iii) age of the patient between 9 and 15 years and (iv) skeletal Class I, considered ANB angle between 0° and 4°. Patients were excluded if they had (i) any disease that could have influenced normal skeletal development, (ii) poor quality X-rays and (iii) absence of informed consent for the use of diagnostic records for scientific purposes. All patients who underwent orthodontic treatment from January 2016 to August 2022 following the inclusion and exclusion criteria and were selected for the analysis.

The age range was selected by considering the current evidence. According to Baccetti et al's study, 9-year-old males are highly likely to be in a pre-pubertal phase of growth, whereas 14-year-old girls are predominantly in a post-pubertal stage of development.[18] Therefore, we did not include patients under 9 years of age and over 15 years of age. Execution of middle finger radiographs followed a standardized protocol and was performed by trained residents of the Postgraduate School of Orthodontics of the University of Trieste. Briefly, the patient's hand was spread on a flat hard surface. The right hand was chosen for the investigation of all the patients, to standardize as much as possible the procedure, even though evidence shows total agreement of staging between the left and right hand.[19] The middle phalanx of the third finger is centred on a 3×4 cm periapical sensor (Dürr Dental). The cone of the dental X-ray machine (Kodak 2200 intraoral X-ray system; Eastman Kodak Company) is positioned perpendicular to the periapical sensor and in light contact with the middle finger (Figure 1). The X-ray machine was set at 70 kV and 7 mA with an exposure time of 0.097 s. Film processing was performed with an automatic developer (VistaScan PERIO; Dürr Dental).

Once collected, the X-rays were classified by a trained orthodontist (LC), blinded to correspondence between diagnostic record and patient and according to the 5-stage MPM system modified by Perinetti in 2017.[4] Data were anonymously collected in a computerized spreadsheet, and chronological ages were used to derive the duration of each stage from MPS2 to MPS4. Considering that patients were included in the study regardless of their MPS stage at the first recording (T_0) and for a variable follow-up time, to avoid a biased calculation, the duration of a stage was possible only if the following one was achieved in the follow-up period, that is, if at least three stages were changed in the monitoring period. For simplification of data analysis, chronological months were converted to decimal values by dividing them by 12 (eg 11 months = 11/12 = 0.92; 10 months = 10/12 = 0.83).

For age at the beginning of stages, criteria on when a patient could be included in the analysis were less stringent. For each stage, a patient was included if a change in stage happened between two 6-month recordings. Once again, stages were considered separately, and each patient was included in the calculation of every stage he/she presented. An example of the study design and selection procedure is presented in the Figure S1.

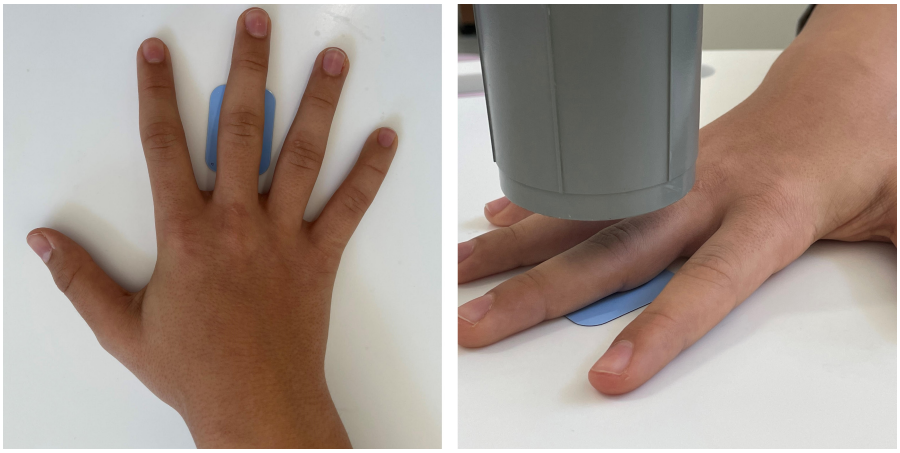

FIGURE 1 Exact position of the patient's hand to perform a X-ray of the middle phalanx of the third finger.

2.1 | Statistical analysis

The repeatability in MPM stage assignment on 24 randomly chosen patients was evaluated using the percentage of agreement and by both unweighted and linear weighted kappa coefficients[20] (Table S1). The kappa coefficient ranges from 0 for no agreement to 1 for perfect agreement. Statistical analysis was performed with IBM SPSS Statistics (version 26). Median, Quartiles and Minimum and Maximum values were calculated for the duration of each MPM stage from MPS2 to MPS4, while mean values, standard deviations, 95% confidence intervals and minimum and maximum values were calculated for the age at the beginning of each MPM stage from MPS2 to MPS5. The Shapiro-Wilk test was used to verify the failure of the normality assumptions, and the Mann-Whitney *U* test was used to test the significance of the difference between the duration of each stage and the age at the beginning of the stages between the sexes. An adjunctive point biserial correlation coefficient was calculated for both the duration of the stages and the age at the beginning with respect to the sexes, to account for the different sample sizes between males and females. The *P*-value was set at .05.

Supposing an effect size of 0.77, with an alpha level of 0.05 and $1-\beta = 0.80$, the required sample size was 29 patients for the group, calculated for the main aim of investigating the differences between the sexes in the duration of stages. Data were acquired from a previous pilot study (L Pozzan, G Zentilin, G Ulian, L Contardo, unpublished data). The a priori sample size required was calculated with G*Power (version 3.1.9.7).

3 | RESULTS

The overall percentage of agreement for the MPM stages was 88%. The unweighted kappa coefficient was .84, and the weighted kappa coefficient was .92. A total of 246 patients were selected from the database, 102 females and 144 males. Ninety-four patients were considered for the calculation of the duration of stage MPS2 (32 females and 62 males), considering subjects who, during the monitoring time, went through at least stages MPS1, MPS2 and MPS3. Ninety-four patients were considered for the duration of stage MPS3 (39 females and 55 males), considering patients who went through at least stages MPS2, MPS3 and MPS4 during the monitoring time. The number of subjects for the duration of stage MPS4 was reduced to 57 (31 females and 26 males), those being patients with at least one record for stages MPS3, MPS4 and MPS5. Each stage was analysed separately, so each patient could be considered for the duration of more than one stage, depending on the skeletal phase he/she went through during the monitoring time. Figure S1 aids in the understanding of patients' selection and study design. The duration for each stage from MPS2 to MPS4 irrespective of sex is summarized in Table 1. In the sample analysed, no subject skipped stages. A clinical example of a patient (patient no. 36, female) that transitioned through every stage is shown in Figure 2.

Considering the sexes separately, both males and females show a median duration of stages MPS2 and MPS3 of 1 year, while for MPS4, females show once again a median duration of 1 year and males of 9 months. The number of subjects considered and the median, quartiles and minimum and maximum values in decimals are summarized in Table 2. No significant results were found for the difference in duration of stages MPS2, MPS3 and MPS4 between males and females, and the values of the point biserial correlation

TABLE 1 Duration of stages from MPS2 to MPS4 considering sexes together. Numerical values are expressed in decimals.[a]

	MPS 2	MPS 3	MPS 4
N	94	94	57
Median	1.00	1.00	1.00
Q1	0.5	0.5	0.5
Q3	1.5	1.00	1
Min	0.5	0.5	0.5
Max	3	3	2

[a]MPS indicates third finger middle phalanx maturational stage; N, number of subjects; Q1, first quartile; Q3, third quartile; Min, minimum; Max, maximum.

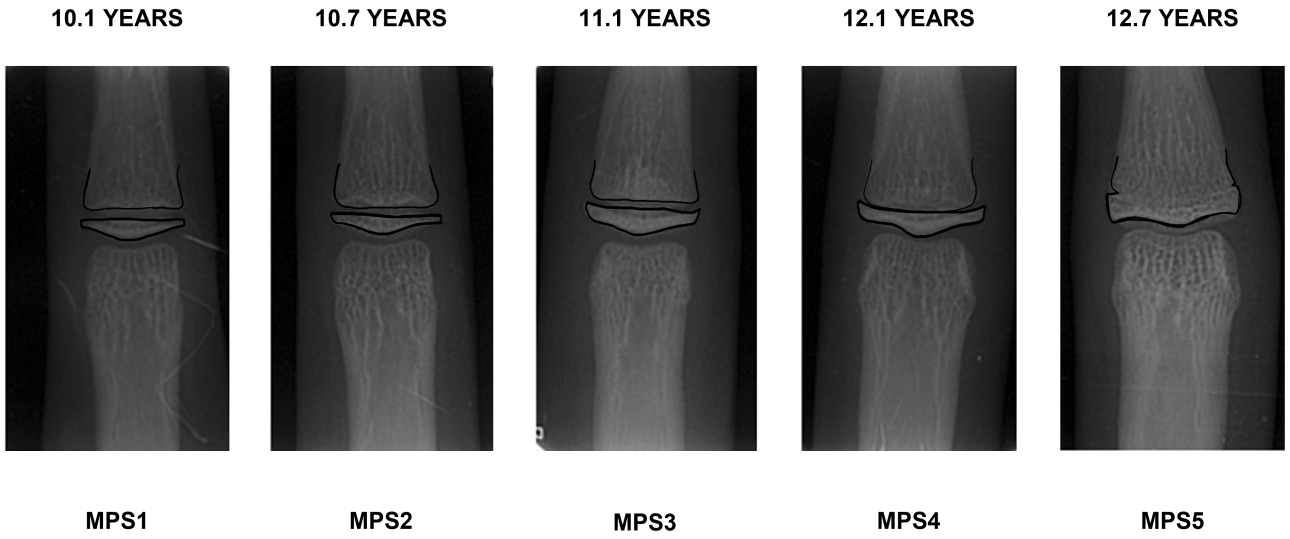

FIGURE 2 Clinical example of patient no. 36 (female) showing transition through every stage of the Middle Phalanx Maturation method.[12] MPS: third finger middle phalanx maturational stage.

	MPS2		MPS3		MPS4	
	F	M	F	M	F	M
N	32	62	39	55	31	26
Median	1.00	1.00	1.00	1.00	1.00	0.75
Q1	0.5	0.5	1.00	1.00	0.5	0.5
Q3	1.0	1.5	0.5	1.00	1.00	1.00
Min	0.5	0.5	0.5	0.5	0.5	0.5
Max	3.0	2.5	2.0	3.0	2.0	2.0
Sign	NS		NS		NS	

TABLE 2 Duration of stages from MPS2 to MPS4 considering sexes separately. Numerical values as expressed in decimals. Mann-Whitney *U* test was used to assess the significance of the difference between the sexes in the duration of each stage ($P \leq .05$)[a].

[a]MPS indicates third finger middle phalanx maturational stage; F, females; M, males; SD, standard deviation; Min, minimum; Max, maximum; Sign, significance; NS, non-significant.

coefficient $r_{(pb)}$ confirm the absence of correlation between the duration of the stages and sex.

Table 3 shows the age at the beginning of each stage from MPS2 to MPS5 divided according to sex (Table 3). The age at the beginning of the four stages was 10y11m, 11y8m, 12y9m and 13y4m for females and 11y11m, 13y1m, 13y11m and 14y3m for males. For each stage, the difference between males and females was statistically significant ($P \leq .001$). To confirm this result, it was found that the age at the beginning of MPS2, MPS3, MPS4 and MPS5 was moderately positively correlated with sex (for MPS2; $r_{(pb)}(121) = .47$, $P = <.01$; for MPS3, $r_{(pb)}(158) = .6$, $P < .01$; for MPS4, $r_{(pb)}(121) = .58$, $P < .01$; for MPS5, $r_{(pb)}(60) = .53$, $P < .01$).

Regarding the duration of stages, some outliers were recorded for each stage. MPS2 lasted 2 years in 2 subjects (7F and 16F) and 3 years in one patient (31F). No outliers for MPS2 were recorded in males. MPS3, in males, lasted 2 years in 4 subjects (19M, 22M, 81M and 108M) and 3 years in only 1 subject (4M). Duration of MPS3 for females was more scattered, with 4 patients (101F, 105F, 115F and 136F) having a duration of 0.5 years, 4 patients (61F, 62F, 66F and 72F) a duration of 1.5 years and 2 patients (97F and 36F) of 2 years. Finally, only 1 male outlier (87M) and 1 female outlier (97F) were recorded where MPS4 lasted 2 years. Regarding the age at the beginning of the stages, in stage MPS2, the females did not have outliers, while three male subjects were present (180M: 9.0 years; 6M: 9.58 years and 116M: 15 years). For MPS3, only one male outlier was recorded (4M: 10.42 years) and two female outliers, one lower and one upper (72F: 9.25 years and 115F: 14.5 years). No outliers were recorded for age at the beginning of MPS4, while only one male outlier was present in the upper bound (135M: 15.0 years).

4 | DISCUSSION

The present study aimed to investigate the duration of the stages corresponding to the circumpubertal period in the Middle Phalanx Maturation Method (MPM) in a contemporary population. In our sample, the median duration of the stages MPS2, MPS3 and MPS4 was 1 year for females, while in males, MPS2 and MPS3 lasted 1 year

TABLE 3 Age at the beginning of each stage from MPS2 to MPS5 considering sexes separately. Numerical values are expressed as decimals. Mann-Whitney *U* test was used to assess the significance of the difference between the sexes in the age at the beginning of each stage ($P \leq .05$)[a].

	AGE MPS2		AGE MPS3		AGE MPS4		AGE MPS5	
	F	M	F	M	F	M	F	M
N	38	85	61	99	61	62	39	23
Mean	10.91	11.97	11.66	13.07	12.75	13.94	13.36	14.24
SD	0.85	0.98	1.03	0.84	0.96	0.70	0.79	0.49
95% CI (lower)	10.62	11.75	11.40	12.90	12.50	13.76	13.10	14.03
95% CI (upper)	11.18	12.18	11.93	13.24	12.99	14.12	13.61	14.45
Min	9.08	9.00	9.25	10.42	10.67	12.42	11.25	13.42
Max	12.50	15.00	14.50	15.00	15.00	15.00	14.75	15.00
Sign	$P < .001$		$P < .001$		$P < .001$		$P < .001$	

[a]MPS indicates third finger middle phalanx maturational stage; F, females; M, males; N, number of subjects; SD, standard deviation; CI, confidence interval; Min, minimum; Max, maximum; Sign, significance.

and MPS4 lasted 9 months. No differences have been found between the sexes. The MPM method has raised particular interest and has been confirmed to be reliable and accurate,[4] so it is ideal for serial monitoring to follow ossification events.[21] The identification of a defined duration of each MPM stage is fundamental information to optimize the timing of the orthopaedic treatment, and great efforts have been made over the years to give sound results. This task is particularly difficult, mainly due to the great variations between individuals. The effort of this study to collect a large longitudinal sample was carried out to account for these variations. Based on our results, a 6-month follow-up during the circumpubertal period is a good monitoring interval to intercept the main growth events.

Previous investigations tried to answer this question but limited sample size, missed consideration of MPS4 and use of legacy collections influenced by secular trends led to non-definitive answers. In particular, previous investigations that analysed secular changes in the shape and size of the craniofacial complex have found marked differences in growth patterns, even in the absence of changes in absolute size.[17] Additionally, the authors underlined that significant growth differences can occur between birth cohorts that are no more than a few decades apart. As such, results from many previous investigations that used files from the American Associations of Orthodontists Foundation (AAOF) Craniofacial Growth Legacy Collections[4] or samples prospectively collected in previous decades[6,12,22,23] are bound to have been heavily influenced by these growth changes. To account for this problem, this study considered a contemporary population of subjects born between 2001 and 2013. This influence of secular trends also concerns a 2016 investigation by Perinetti et al, who otherwise was closest to identifying the duration of MPM stages.[4] They found that stages MPS2, MPS3 and MPS4 lasted around 1 year, with few exceptions. Since the main objective of this study was different from the one described the duration of MPS2 and MPS3 was derived from a limited subset of patients (25 and 21, respectively), and the duration of MPS4 was analysed in only 5 subjects. With these limitations, no comparison between males and females could be made. The strong increase in the sample size of this study and the evaluation of a contemporary population directly aimed to overcome all these limitations.

The relevant size of this longitudinal record collection allowed us to calculate ages at the beginning of stages from MPS2 to MPS5. Even though chronological age has been ruled out for its use as a sole indicator of skeletal growth,[1,24] the identification of confidence intervals within which each growth phase is allocated could still find application in medical fields beyond orthodontics, such as forensic and humanitarian medicine.[25] This study confirms the earlier skeletal development of females compared to males, on average 1 year. Considering other indicators of the timing of puberty, our results seem to fit in between the first signs of puberty and the peak of pubertal growth velocity, based on Tanner Stages.[26,27] For females, the first sign of puberty is represented by the initiation of breast development, classified as Tanner stage 2, and between Tanner stage 2 and 3 of breast development, they experience peak height velocity.[26,28–30] In a population with a similar ethnic profile to the one considered in our study, these stages occur at 10.32 and 12.36 years of age, respectively.[31] In our study, the age at the beginning of MPS2 and MPS3—the stages corresponding to the onset and maximum mandibular pubertal growth spurt—is located between the two Tanner stages, at 10.91 and 11.66 years. The same pattern can be observed for males. In this case, the first external signs of puberty are an increased testicular volume and Tanner's genital growth stage 2 (G2), while peak height velocity occurs during Tanner Stage 3 genital development (G3).[27,32] G2 occurs at a mean of 11.2 years and G3 at 12.57.[33] Similar to what happens for females, in our study, the beginning of MPM Stages 2 and 3 are situated between the limits of the standard deviations of the two Tanner stages 2 and 3, precisely at 11.97 and 13.07 years of age.

The main limit of this study is its design: even though a great effort was made to collect a longitudinal sample, the patients were included at T_0 regardless of their initial MPS stage. Being able to follow all patients from MPS1 up to MPS5 will better suit this type

of data. Future investigations could vary inclusion and exclusion criteria to achieve this goal. Another limitation of this investigation is the drop-out rate at stage MPS4. The reduction in sample size can be attributed to the average duration of the orthodontic therapy. Many patients, after an average period of 2 years, cannot be further monitored because they have completed their treatment, so the execution of more X-rays is not indicated, although stage MPS4 represents the deceleration of skeletal growth after the pubertal spurt and a certain residual growth is still present.[24] That being said, despite the reduction, the sample size remains high enough to support the statistical power of the analysis.

5 | CONCLUSIONS

- The Middle Phalanx Maturation method is a simple and effective method to be implemented in everyday clinical practice.
- Each circumpubertal stage from MPS2 to MPS4 last around 1 year.
- A relevant interindividual variability is confirmed for the duration of stages, with even greater values for age at the beginning of each stage.
- A 6-month to 1-year interval is considered a good interval between the third finger middle phalanx X-ray to accurately monitor the pubertal growth spurt in orthodontic patients.

AUTHOR CONTRIBUTIONS

LP: Formal analysis, investigation, writing—original draft preparation; GZ: investigation, validation; GU: Investigation, Validation; LC: Conceptualization, Supervision, Writing—Reviewing and Editing.

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CONFLICT OF INTEREST STATEMENT

All authors have completed and submitted a COI Disclosure Form for disclosure of potential conflicts of interest, and none were reported.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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