Brief Communication

Diagnostic performance of eruption stages for identification of skeletal maturity

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ABSTRACT

Objectives: To investigated the diagnostic performance of circumpubertal eruption stages which identify skeletal maturity stages using the cervical vertebral maturation (CVM) method in a Saudi population.

Methods: This is a retrospective cross-sectional study. Lateral cephalograms, panoramic radiographs, and intraoral pictures of 600 orthodontic patients (284 boys, 316 girls) who met inclusion criteria were assessed. Records were retrieved between January 2016 and April 2018. The diagnostic performance of eruption stages for identifying skeletal maturity was tested with positive likelihood ratios (LHR+).

Results: Prevalence of each CVM stage in the eruption stages was reported. For every eruption stage, LHR+ was reported in order to identify every CVM stage. The majority of the LHR+ values were ≤3.5, with a significant value of ≥10 for the identification of the post-pubertal growth stage. The other eruptions stages did not strongly predict skeletal maturity.

Conclusion: In treatment planning for cases that require identifying the growth peak, the use of eruption stages is not recommended as an indicator of skeletal maturity except for the early permanent dentition stage where strong diagnostic performance for identifying post-pubertal skeletal growth stage has been shown.

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The ideal timing of growth modification in cases of maxillomandibular disharmony is critical to achieve a favorable outcome.[1,2] Favorable outcomes are seen in cases of maxillary deficiency when orthopedic treatment is carried out before pubertal growth spurt, which is in contrast to cases of mandibular deficiency when treatment is carried out during the pubertal growth spurt.[1]

Skeletal age has been, and still is, the standard measure for identifying the inception of the pubertal growth spurt. For this reason, many studies have investigated multiple potential indicators of skeletal maturity.[3-5] Some of these indicators, such as chronological age,[3] proved unreliable, while others, such as dental maturity (tooth-formation stages)[4,5] of permanent lower canines and second molars, has shown limited reliability. Researchers have argued that studying the relationship between stages of dentition, or dental eruption (teeth entering the oral cavity and becoming visible), and skeletal maturity is useful in clinical practice and for interpreting results of studies reporting treatment outcomes at different dentition stages.[6,7] They found certain stages of dentition to have strong diagnostic value for identifying certain levels of skeletal maturity.[6]

This relationship has not been explored in people living in Saudi Arabia, an ethnically distinct population from those previously reported. This is a relevant issue because dental maturity and eruption have a delayed timing when compared to that of Caucasians.[8,9] Therefore, this study investigated the diagnostic performance of circumpubertal eruption stages for identifying skeletal maturity stages in a Saudi population.

Methods. This was a cross-sectional, retrospective study that included lateral cephalograms, panoramic radiographs, and intraoral pictures of 600 conveniently selected orthodontic patients (284 boys, 316 girls). These records were collected from the database of the Department of Orthodontic, King Abdulaziz University Faculty of Dentistry (KAUFD), Jeddah, Saudi Arabia between January 2016 and April 2018. Both radiographs were acquired on the same day. Records with adult permanent and full deciduous dentition were excluded because patients were not close to puberty (circumpubertal). Records of patients with craniofacial or dental anomaly were excluded as well. The sample had 150 subjects in each of the eruption stages. The study was conducted according to principles of the Declaration of Helsinki.

PubMed and Google Scholar were used to search for all previously published relevant articles. Only articles that were published in English were included. Efforts were made to include only recent articles published within the last 5 years. However, some older articles were relevant and included. The eruption stages were assessed using panoramic radiographs and intraoral pictures. The staging followed the methods proposed by Bjoerk et al,[10] Van Der Linden and Duterloo,[11] which categorize eruption stages as follows: 1) early mixed, starts with the loss of the primary incisors and the eruption of the permanent incisors and the first molars; 2) intermediate mixed, occurs with the full eruption

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of the permanent incisors and the first molars in the presence of the primary canines and the first and second molars; 3) late mixed, deciduous canines and the molars shed, and the permanent canines erupt; and 4) early permanent, when the dental arch has permanent teeth with the second molars being possibly present and the third molars being possibly absent.

Skeletal maturity assessment. In orthodontics, skeletal age is evaluated using a variety of measures. The most commonly used is cervical vertebral maturation (CVM).[12] The method of Baccetti et al[1] was used in CVM assessment where the cervical stages (CS) are determined by assessing the lower borders of the first 3 vertebrae (C1, C2, and C3) and the C3 and C4 bodies as shown in the original article. Briefly, the first 2 stages (CS1 and CS2) indicate a prepubertal stage of skeletal maturity. The third stage (CS3) signifies the inception of pubertal growth, while the later stages (CS4, CS5, CS6) indicate the end of pubertal growth. The examiner was blinded to the eruption stages while scoring the lateral cephalogram to assess skeletal maturity.

Statistical analysis. The prevalence of each CVM stage in each of the 4 stages of eruption was calculated. The clinical performance of each eruption stage (test) for the diagnosis of each CVM stage (condition) was established by calculating the positive likelihood ratios (LH+) using sensitivity, specificity, and 95% confidence intervals (CIs).[13] Positive likelihood ratios indicate a given test result in people who have the condition. In this study, an LH+ for a given eruption stage provides an estimate of the odds of having a given skeletal stage. A satisfactory diagnostic performance occurs when the LH+ is equal to or more than 10.

To asses inter-rater reliability, kappa statistics and percent agreement were measured for 40 randomly chosen records. For CVM stage evaluation, the kappa statistic was 0.93 with percent agreement of 95.4%, and for the eruption stage evaluation, the kappa statistic was 0.99 with percent agreement of 97.3%. Statistics were performed by Statistical Package for Social Sciences for Windows, version 25 (IBM Corp., Armonk, NY, USA). Data were initially analyzed for each gender, but eventually combined due to the similarity of results.

Results. A total of 284 boys and 316 girls between the ages of 7 and 15 were included in the study. The prevalence of each CVM stage in each of the eruption stages is shown in **Table 1**. For the early and intermediate mixed stages, the prepubertal skeletal maturity stage CS1 was the most prevalent. Both the prepubertal stage (CS1) and the inception of pubertal growth stage (CS3) were almost equally prevalent for the late mixed stage, while the early permanent stage was most prevalent for CS3.

The LH+ values and 95% CIs for every eruption stage with respect to the identification of each CVM stage (**Table 2**). The majority of the LHR+ values were ≤3.5 and a value of ≥10 was found only for identifying the post-pubertal growth phase (CS5 and CS6) for early permanent dentition (LH+, 13.7 and 46.3). In the early and intermediate mixed dentition stages, higher LH+ values were observed for prepubertal growth stages (CS1 and CS2) compared to the pubertal growth stage (CS3), while no subjects were in a post-pubertal growth stage. This might indicate that a subject who is in the early or intermediate mixed dentition stages has a somewhat higher probability to be in the prepubertal growth stages, and a lower probability of being in the post-pubertal stage. For the late mixed dentition stage, greater LH+ values were observed for the pubertal growth stages as compared to the prepubertal and post-pubertal growth stages.

Table 1 - Prevalence of each cervical vertebral maturation stage during each stage of eruption (N=600).

Eruption stages	CS1	CS2	CS3	CS4	CS5	CS6
Early mixed (n=150) M:26 F:22	105 (70.0)	27 (18.0)	18 (12.0)	0	0	0
Intermediate mixed (n=150) M:37 F:38	78 (52.0)	40 (26.7)	18 (12.0)	14 (9.3)	0	0
Late mixed (n=150) M:83 F:66	45 (30.0)	27 (18.0)	28 (18.7)	43 (28.7)	5 (3.3)	2 (1.3)
Early permanent (n=150) M:128 F:134	12 (8.0)	13 (8.7)	13 (8.7)	58 (38.6)	23 (15.3)	31 (20.7)

Values are presented as numbers and percentage (%).

Table 2 - Diagnostic performance of the eruption stages in determining the cervical vertebral maturation (CVM) stage.

Stages	Sensitivity (95% CI)	Specificity (95% CI)	LHR+ (95% CI)
Early mixed eruption stage			
CS1	70% (62-77.2%)	69.9% (65.4-74%)	2.3% (2-2.8%)
CS2	18% (12.2-25.1%)	82.1% (78.3-85.6%)	1% (0.7-1.5%)
CS3	12% (7.3-18.3%)	86.9% (83.3-89.9%)	0.9% (0.5-1.5%)
CS4	0 % (0-2.4%)	74.8% (71-78.8%)	-
CS5	0% (0-2.4%)	93.7% (91-95.9%)	-
CS6	0% (0-2.4%)	92.7% (89.9-94.9%)	-
Intermediate mixed eruption stage			
CS1	52% (43.7-60.2%)	663.9% (59.2-68.3%)	1.4 (1.2-1.7)
CS2	26.7% (19.8-34.5%)	85% (81.4-88.2%)	1.8 (1.3-2.5)
CS3	12% (7.3-18.3%)	86.9% (83.3-89.9%)	0.9 (0.5-1.5)
CS4	9.3% (5.2-15.2%)	77.9% (73.8-81.7%)	0.4
CS5	0% (0-2.4%)	93.7% (91-95.9%)	-
CS6	0% (0-2.4%)	92.7% (89.9-94.9%)	-
Late mixed eruption stage			
CS1	30.4% (23.1-38.5%)	56.7% (51.9-61.3%)	0.7 (0.54-0.92)
CS2	18.2% (12.4-25.4%)	82.2% (78.4-85.6%)	1 (0.69-1.52)
CS3	14.8% (10-20.7%)	89.1% (85.9-91.8%)	1.4 (0.9-2.1)
CS4	28.7% (21.6-35.6%)	84% (80.3-87.3%)	1.8 (1.3-2.5)
CS5	3.4% (1.1-7.7%)	94.9% (92.4-96.7%)	0.6 (0.2-1.7)
CS6	1.3% (0.2-4.8%)	93.1% (90.4-95.3%)	0.2 (0.1-0.8)
Early permanent eruption stage			
CS1	8% (4.2-13.6%)	49.1% (44.4-53.8%)	0.2 (0.1-0.3)
CS2	8.7% (4.7-14.4%)	79% (74.9-82.7%)	0.4 (0.2-0.7)
CS3	50% (29.9-70.1%)	85.7% (82.1-88.8%)	3.5 (2.2-5.5)
CS4	38.7% (30.8-46.9 %)	87.7% (84.3-90.6%)	3.1 (2.3-4.3)
CS5	15.3% (10-22.1%)	98.9% (97.4-99.6%)	13.7 (5.3-35.5)
CS6	20.7% (14.5-28%)	99.5% (98.4-99.9%)	46.3 (11.2-191.1)

CI - confidence interval, LHR+ - likelihood ratios

Discussion. Using eruption stages as indicators of skeletal maturity offers a simple and convenient chairside method for orthodontists to estimate the timing of the pubertal growth spurt and eventually make decisions about growth modification. Several investigators have shown interest in this relationship. They have reported promising correlations with mixed results when it comes to the diagnostic performance of eruption stages in the identification of skeletal maturity.[6,14,15] The relationship between skeletal development and eruption stages may vary with ethnicity and race.[8,9] Therefore, it makes sense to investigate these features in each ethnicity of interest. This study explored the usefulness of eruption stages as indicators of the skeletal maturity level in a Saudi Arabian sample.

The current study showed that the early permanent eruption stage had a reliable diagnostic performance for identifying post-pubertal skeletal maturity ration stages as shown by the above-threshold LH+ of 13.7 for CS5 and 46.3 for CS6. Thus, the eruption stage characterized by an all-permanent dentition in the absence of the wisdom teeth is a powerful indicator of the postpubertal stage. On the other hand, each of the other eruption stages correlated with one of the skeletal maturity stages, but with an unsatisfactory diagnostic performance. Unfortunately, this included the prepubertal and pubertal stages, which are the most critical stages to identify in orthodontic/orthopedic treatment planning cases for maxillary and mandibular deficiency.

Previous studies in North America, Europe, and Iran have reported good performance of the early mixed dentition stage for identifying the prepubertal stage of skeletal maturity.[6,14] This was not the case in this study. Although 88% of subjects at the prepubertal skeletal maturity stage had early mixed dentition, the likelihood ratio was not high enough for it to be used as a diagnostic marker. The implication of this study is that the eruption stage cannot be incorporated into the decision-making scheme with regards to maxillomandibular growth modification. Therefore, one has to resort to more reliable methods, such as a lateral cephalography to assess CVM and hand-wrist x-rays. These methods obviously have the disadvantages

of exposure to radiation, unavailability of radiography equipment, and the lack of the practicality of a chairside assessment. Therefore, future research is needed to investigate the utility of other clinical measures to predict skeletal maturation stage.

Study limitation. There are several limitations to the generaliability. of the study's findings. The sample was entirely drawn from subjects from the Western region of Saudi Arabia. The population of Saudi Arabia varies in terms of its ethnic composition across different regions. As such, the findings are specific for Saudi individuals in the Western region. Additional studies may be needed to ascertain whether the current findings hold true in other regions. Another limitation of the study has to do with using eruption stages as a diagnostic method. Although eruption is under significant control of genetics, it may be affected by a myriad of systemic and local factors, including but not limited to, nutrition, tooth size-arch length discrepancy, dental caries, early tooth loss, and many other factors. Having said that, using tooth formation stages has shown limited reliability,[4,5] while promising correlations were shown when using diagnostic performance of eruption stages in the identification of skeletal maturity.[6,14,15]

Based on these results, it could be concluded that the early permanent stage of eruption showed strong diagnostic accuracy for predicting of the cessation of the pubertal growth spurt. On the other hand, the data demonstrated that mixed dentition stages have limited clinical usefulness for identifying prepubertal (CS1 and CS2) and post-pubertal (CS4, CS5, and CS6) skeletal maturity stages. Further research is needed to identify a reliable and sufficiently predictive clinical parameter to predict skeletal maturity and guide maxillomandibular growth modification.

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