Dental Age Estimation Using Periodontal Ligament Visibility and Root Pulp Volume at the 18-Year Threshold in the Chinese Population

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Abstract: Background: The concept of comparing “chronological age” vs. that of “dental age” has been well documented. Considering ethnic variations in dental development, the use of population-specific standards for age estimation has been emphasized. Mandibular maturity markers have been successfully employed to estimate the age of a person at the 18-year threshold. No such data are available for the Chinese population, which represents around one-fifth of the global human population. Aim: The aim of this research project was to analyze and grade mandibular third molars using maturity markers in the Chinese population. Materials and Methods: In total, 882 panoramic radiographs (424 females and 458 males) of 16- to 24-year-old Chinese children and young adults were obtained from patient archives. All patients were graded by a trained and calibrated examiner using stages A-D for mandibular maturity markers including Periodontal Ligament Visibility (PLV) and Root Pulp Volume (RPV). Results: The average Age at Assessment (AaA) ranged from 18.79 years for females in Stage A of PLV to 21.59 years for females in Stage D of PLV. The AaA was not statistically significant between females and males across all the stages, for both PLV and RPV. For PLV, the percentage of females below 18 years was 57.14% in Stage A and 17.14% in Stage D. For males, it was 48.84% in Stage A and 14.93% in Stage D. For RPV, the percentage of females below 18 years was 54.72% in Stage A and 12.73% in Stage D. For males, it was 49.09% in Stage A and 14.81% in Stage D. On average, for PLV, 85.30% of subjects were over 18 years of age in Stages C and D, and for RPV, 82.50% subjects were over 18 years of age in Stages C and D. Conclusions: Both RPV and PLV are considered as reliable maturity markers to estimate the age of Chinese subjects in the 18-year threshold. No difference was observed in the average Age at Assessment of mandibular maturity stages between the sexes.

Keywords: age estimation; dental development; Chinese; maturity markers; periodontal ligament visibility; root pulp volume

1. Introduction

Various studies have looked at the relationship between an individual’s chronological or true age and their dental age, based upon eruption and tooth development. It is possible to deduce a lot of background information about a person from given dental records [1]. Thus, the following question arises: are we able to use dental information to estimate a person’s true age? This is especially true in circumstances where we do not have information about a person’s background or when other skeletal remnants cannot be used [2]. This is particularly important at the 18-year-old threshold, which is considered as the age of majority in several countries [3]. Third molars are the only available teeth for conducting dental age estimation at this threshold, as all other permanent teeth would have completed development. It is suggested that the third molar can be used as a reflection of one’s dental age even beyond this threshold, and many studies have conducted research from maturity...
markers of mandibular molars [4]. This is specifically true with the four-stage methodology of the mandibular third molar based on Root Pulp Volume (RPV) and Periodontal Ligament Visibility (PLV) [4,5]. The four-stage methodology for Root Pulp Volume (RPV) was first developed by Olze in stages 0, 1, 2, and 3. Olze’s paper was then used as a basis of the analysis carried out by Lucas et al. study [4], wherein the stages were re-labeled as A, B, C, and D for both RPV and Periodontal Ligament Visibility (PLV) [4–6]. These stages were subsequently derived from an eight-stage system of development (from A to H), where in order to analyze the third molar, the molar should have achieved stage H of development [2,4,5]. Stage H should visually represent closed apices and an apparent periodontal ligament space [2]. The accuracy of the dental age depends on the specific subgroups being analyzed [7].

The Chinese represent around one-fifth of the human population, making it the second most populous country in the world [8]. It has been suggested that utilizing dental information could be “one of the most reliable methods” for age estimation [9]. Forensic records, especially as migration increases, are needed to accurately determine the age of those who do not have access to their chronological age, or true age [10]. As such, it has been highlighted by sources that “a population specific Reference Data Set (RDS)” is needed for this ethnicity [10]. Moreover, it has been noted that current data sets of other ethnicities and populations cannot be validly applied to this subgroup in all realms of comparison [10]. Even current RDSs for the southern Han Chinese can only be applied in a limited way to other East Asian subgroups, most specifically to the Japanese [11].

Most of the age estimation studies in the Chinese population only looked at the development status of the tooth, which limits its application up until 18 years [10,11]. The studies found that we could estimate whether a patient was below or above the age of 18 years by looking at the PLV and RPV of the third molars [4,5]. Individuals younger than 18 would be classified into stage A and B, whereas individuals older than 18 would be classified into the later stages of C and D [4,5]. The aim of this study was to analyze and grade mandibular third molars using maturity markers in the Chinese population. The secondary objectives were to assess if the maturity markers (PLV and RPV) can identify the age of the subjects in the 18-year threshold, and to also evaluate sex differences in the maturity markers.

2. Materials and Methods
A total of 882 (424 females and 458 males) panoramic radiographs were scored from patient archives at the dental school associated with the University of Hong Kong, where ethics approval was obtained (IRB: UW 12-280). The secondary analysis of de-identified radiographs was previously obtained for a study on the development of dental reference standards for age estimation by Jayaraman et al. [10]. The representative sample belongs to those of Han Chinese ethnicity in Hong Kong, a special administrative region of China. The age of the subjects included in the study ranged from 16 years up to 24 years, and subjects were further divided into female and male subgroups with an average of around 50 subjects in each age group. Out of 900 radiographs, around 18 radiographs were excluded from the study due to (1) artifact or exposure issues present on the radiographs, which made the reading of the PDL or RPV stages difficult, or (2) the lack of patient identification on the radiographs for analysis. As previously indicated, the left mandibular third molar was chosen as the tooth to be evaluated. If missing, the right mandibular third molar was evaluated instead. Each radiograph was graded and analyzed for RPV and PLV by a trained and calibrated examiner (W.K.). For calibration purposes, around 5% of panoramic radiographs were scored by two examiners (W.K. and J.J.) for intra- and inter-examiner reliability, at a 2 week interval using Kappa analysis [12].

Data were manually entered into an excel spreadsheet. Each patient’s ID number, date of birth (DOB), date on which the panoramic was taken (DOR), CA (calculated or true age), PLV (Periodontal Ligament Visibility), and RPV (root pulp visibility) were recorded, respectively. Some identification information could not be found for certain radiographs.
based on radiographic exposure or scanning errors. Radiographs were graded based on four categories for PLV—PLV A; PLV B; PLV C; and PLV D (Figure 1)—and four categories for RPV—RPV A; RPV B; RPV C; and RPV D (Figure 2). The exact visual representations of the stages were used from Lucas et al. study [4]. Both research papers contained visual representations of what each stage would ideally look like and were, respectively, utilized as a guide to analyze and grade the panoramic images. For RPV, earlier stages show more root pulp in comparison to the later stages, which showed partial pulp coverage on the root(s); for PLV, earlier stages showed more periodontal ligament as a well-defined corticated radiolucent border around the tooth in comparison to the later stages. Statistical significance was set at $p < 0.05$ and an independent sample t-test was conducted to assess the average Age at Assessment of the stages in PLV and RPV between females and males.

![Figure 1. Illustration of Periodontal Ligament Visibility (Lucas et al., 2017) [5].](image-url)
3. Results

Based on the Kappa analysis, the intra-examiner reliability score for the first examiner (W.K.) was 0.86 and the inter-examiner reliability score between the examiners (W.K. and J.J.) was 0.81, corresponding to “almost perfect” agreements [12].

For PLV, the average Age at Assessment (AaA) ranged from 18.79 years for females in Stage A of PLV to 21.59 years for Stage D for females (Table 1). For RPV, the average Age at Assessment (AaA) ranged from 18.93 years for females in Stage A of PLV to 21.24 years for Stage D females (Table 2). For PLV, the percentage of females below 18 years was 57.14% in Stage A and 17.14% in Stage D (Figure 3). For males, it was 48.84% in Stage A and 14.93% in Stage D (Figure 4).

<table>
<thead>
<tr>
<th>Periodontal Ligament Visibility</th>
<th>Females</th>
<th>Mean</th>
<th>Count</th>
<th>Min</th>
<th>Max</th>
<th>SD</th>
<th>p-Value *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage A</td>
<td></td>
<td>18.79</td>
<td>42</td>
<td>16.03</td>
<td>24.87</td>
<td>2.808</td>
<td>-</td>
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<tr>
<td>Stage B</td>
<td></td>
<td>20.42</td>
<td>144</td>
<td>15.99</td>
<td>25.40</td>
<td>2.749</td>
<td>-</td>
</tr>
<tr>
<td>Stage C</td>
<td></td>
<td>20.70</td>
<td>160</td>
<td>16.06</td>
<td>24.72</td>
<td>2.270</td>
<td>-</td>
</tr>
<tr>
<td>Stage D</td>
<td></td>
<td>21.59</td>
<td>35</td>
<td>16.79</td>
<td>26.45</td>
<td>2.966</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1. Average Age at Assessment for Periodontal Ligament Visibility (PLV) stages.
Table 1. Cont.

<table>
<thead>
<tr>
<th>Periodontal Ligament Visibility</th>
<th>Males</th>
<th>Mean</th>
<th>Count</th>
<th>Min</th>
<th>Max</th>
<th>SD</th>
<th>p-Value *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage A</td>
<td>19.35</td>
<td>43</td>
<td>16.10</td>
<td>24.70</td>
<td>2.911</td>
<td>0.369</td>
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<tr>
<td>Stage B</td>
<td>20.25</td>
<td>137</td>
<td>16.02</td>
<td>25.96</td>
<td>2.891</td>
<td>0.623</td>
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<tr>
<td>Stage C</td>
<td>20.61</td>
<td>309</td>
<td>16.04</td>
<td>25.96</td>
<td>2.483</td>
<td>0.908</td>
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</tr>
<tr>
<td>Stage D</td>
<td>21.09</td>
<td>67</td>
<td>16.10</td>
<td>25.36</td>
<td>2.674</td>
<td>0.398</td>
<td></td>
</tr>
</tbody>
</table>

*p-value based on independent sample t-test.

Table 2. Average Age at Assessment for Root Pulp Volume (RPV) stages.

<table>
<thead>
<tr>
<th>Root Pulp Volume</th>
<th>Females</th>
<th>Mean</th>
<th>Count</th>
<th>Min</th>
<th>Max</th>
<th>SD</th>
<th>p-Value *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage A</td>
<td>18.93</td>
<td>70</td>
<td>16.03</td>
<td>24.73</td>
<td>2.281</td>
<td>-</td>
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<tr>
<td>Stage B</td>
<td>19.74</td>
<td>54</td>
<td>15.99</td>
<td>26.40</td>
<td>2.716</td>
<td>-</td>
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<td>Stage C</td>
<td>20.66</td>
<td>92</td>
<td>16.46</td>
<td>25.54</td>
<td>2.411</td>
<td>-</td>
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<tr>
<td>Stage D</td>
<td>21.24</td>
<td>165</td>
<td>16.04</td>
<td>26.45</td>
<td>2.611</td>
<td>-</td>
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</table>

<table>
<thead>
<tr>
<th>Root Pulp Volume</th>
<th>Males</th>
<th>Mean</th>
<th>Count</th>
<th>Min</th>
<th>Max</th>
<th>SD</th>
<th>p-Value *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage A</td>
<td>19.40</td>
<td>55</td>
<td>16.10</td>
<td>24.67</td>
<td>2.909</td>
<td>0.328</td>
<td></td>
</tr>
<tr>
<td>Stage B</td>
<td>20.31</td>
<td>63</td>
<td>16.02</td>
<td>25.96</td>
<td>2.767</td>
<td>0.264</td>
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<td>Stage C</td>
<td>20.57</td>
<td>114</td>
<td>16.15</td>
<td>24.80</td>
<td>2.249</td>
<td>0.801</td>
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<tr>
<td>Stage D</td>
<td>20.92</td>
<td>189</td>
<td>16.04</td>
<td>25.15</td>
<td>2.566</td>
<td>0.247</td>
<td></td>
</tr>
</tbody>
</table>

*p-value based on independent sample t-test.

For RPV, the percentage of females below 18 years was 54.72% in Stage A and 12.73% in Stage D (Table 2). For males, it was 49.09% in Stage A and 14.81% in Stage D. On average, for PLV, 85.30% of subjects were over 18 years of age in Stages C and D, and for RPV, 82.50% of subjects were over 18 years of age in Stages C and D (Figures 3–6). Both RPV and PLV are considered as reliable maturity markers to estimate the age of Chinese subjects in the 18-year threshold.

Figure 3. Percentage of Chinese females at the 18-year threshold for the Periodontal Ligament Visibility stages.
For RPV, the percentage of females below 18 years was 54.72% in Stage A and 12.73% in Stage D (Table 2). For males, it was 49.09% in Stage A and 14.81% in Stage D. On average, for PLV, 85.30% of subjects were over 18 years of age in Stages C and D, and for RPV, 82.50% of subjects were over 18 years of age in Stages C and D (Figures 3–6). Both RPV and PLV are considered as reliable maturity markers to estimate the age of Chinese subjects in the 18-year threshold.

Figure 4. Percentage of Chinese males at the 18-year threshold for the Periodontal Ligament Visibility stages.

Figure 5. Percentage of Chinese females at the 18-year threshold for the Root Pulp Volume stages.
RPV - Males

Figure 6. Percentage of Chinese males at the 18-year threshold for the Root Pulp Volume stages.

4. Discussion

Our results showed that for both females and males, a greater percentage of individuals above the age of 18 were categorized in the later stages (C and D) as opposed to the earlier stages (A and B) of PLV and RPV development. Likewise, for both females and males, a greater percentage of individuals above the age of 18 were categorized in the later stages (C and D) as opposed to the earlier stages of PLV and RPV development. This is consistent with the results of Lucas et al., 2017 [4,5].

Though the results are consistent with previous studies, Demirjian et al., 1973 brings up a valid point in that the illustrations depicting the stages of development should be paired up with another means of standardization [2]. Though the examiner was calibrated, limitations such as subjectivity and the number of examiners required cannot be overlooked. The stages depicted in Lucas et al.’s study that were used as a guide do not show all the possibilities that each stage can consist of or look like [4,5]. Age estimation using mandibular maturity markers could serve as an additional tool to the database developed by Jayaraman et al. that is based on the stages of dental development in the Chinese population [10].

It is also noteworthy to compare the dental age estimation studies at the 18-year-old threshold using RPV and PLV in other populations such as the British, German, Portuguese, and Turkish. Even though some of these studies have altered staging, the same assessment for the left mandibular third molar can be applied as found in the British population for Lucas et al. [4,5]. In regards to the British population as assessed by Lucas and authors, the population pool included those ranging from 15 to 25.99 years old [4,5]. For RPV, the average age in Stage A and D in females and males was (F: 21.44 and 23.84) and (M: 21.27 and 23.46) [4]. For PLV, the average age in Stage A and D in females and males was (F: 19.57 and 23.86) and (M: 20.32 and 23.37) [5].

While the German study has a subject pool up to the age of 40 years, the average values of when each stage was visible has similar trends to our study and Lucas et al.’s study [4,5,8]. For RPV, at stage 0 (corresponding to stage A) and stage 3 (corresponding to stage D), the average age of visibility was 24.5 years and 35.6 years for females, and 23.5 years and 34.1 years for males, respectively [8]. For PLV, at stage 0 (corresponding to stage A) and stage 3 (corresponding to stage D), the average age of visibility was 21.1 years and 35.7 years for females, and 21.3 years and 33.7 years for males, respectively [8]. The
staging of 0 to 3 for PLV can also be seen for the Portuguese, wherein the subject participant pool ranged from 17 years to 31 years old [13]. For PLV, at stage 0 (corresponding to stage A) and stage 3 (corresponding to stage D), the average age of visibility was 21.6 years and 25.5 years for females, and 19.4 years and 26.9 years for males [13]. These studies highlight that younger individuals are more likely to be found in the earlier stages of RPV and PLV in comparison to the later stages [4,5,8,12,13].

Beyond dental tissues, several other techniques have been reported for age estimation in the 18-year-old threshold. This includes computed tomography of the medial clavicle epiphysis that has been shown to be reliable for subjects aged 15 to 30 years [14]. Similarly, a preliminary study employed magnetic resonance imaging of the distal tibial epiphysis in 8- to 25-year-old subjects with over 90% accuracy in identifying the age beyond 18 years [15]. It may be essential to compare the average Age at Assessment of stages in the Chinese population to non-European ethnicities, including those of other Asian ethnicities. A Turkish study was conducted for participants between the ages of 15 years and 40 years for RPV, where stages 0 to 3 were also utilized for the left mandibular third molar [16]. The average age of visibility was (F: 22.5 and 33.9) and (M: 23.7 and 33.8) [16]. Moreover, a comparison can be made within different regions of China. A study was carried out amongst Northern Chinese subjects between the ages of 15 years and 40 years for PLV of the left mandibular third molar [17]. The average age of visibility for stage 0 and 3 was 24.36 years and 36.49 years for females, and 23.97 years and 36.31 years for males, respectively [17]. In the current study, the age of subjects ranged between 16 years and 24 years, with an equal number of samples across all age ranges. The maximum age of the subjects included in the current study was 24.99 years, which was lower compared to the maximum age of 40 years in other studies [8,13,16,17]. This could be considered as a possible limitation, and future studies could consider including subjects over 25 years for comparison with other current studies. The periodontal ligament is a tissue responding to its function; however, this study did not take into consideration the periodontal ligament changes between the erupted and impacted third molars.

5. Conclusions

Both RPV and PLV are considered as reliable maturity markers to estimate the age of Chinese subjects in the 18-year threshold. No difference was observed in the average Age at Assessment of mandibular maturity stages between the sexes. On average, the percentage of Chinese females over 18 years at stages C and D of Periodontal Ligament Visibility and Root Pulp Volume were 83.36% and 81.68%, respectively. For Chinese males, it was 86.67% and 83.38%, respectively. Overall, 80% of Chinese subjects were over 18 years of age in Stages C and D of mandibular maturity markers.

Author Contributions: J.J. conceptualized and designed the study, coordinated, and supervised data collection. W.K. collected data, carried out the analyses, and drafted the initial manuscript; J.J. performed statistical analyses; J.J. and W.K. critically revised the manuscript. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Conflicts of Interest: The authors declare no conflicts of interest.
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