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The relevance of taurodontism in forensic dental age estimation

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ABSTRACT

Taurodontism is a dental morphological anomaly characterized by enlarged pulp cavities repositioned towards the apical region of the tooth, coupled with shortened root structures. Molars are commonly affected by this alteration. Certain populations exhibit up to 48% prevalences for this dental alteration, underscoring its significance in dental age estimation (DAE). In the field of DAE, an individual's chronological age is inferred from specific dental features, frequently employed within the forensic context.

The effect of taurodontism on the features of DAE is an unanswered issue. The influence of taurodontism on eruption, mineralization, radiographic visibility of root canals, and radiographic visibility of the periodontal ligament space in mandibular third molars- some of the established criteria for DAE as examples-is currently not systematically examined.

Some common staging scales for the dental features of DAE cannot technically be applied to taurodontic teeth.

Additionally, given the association of taurodontism with syndromes affecting tooth development, caution is warranted in age assessment procedures.

Notably, taurodontic teeth may serve as indicators of syndromes influencing skeletal development, further emphasizing the relevance of taurodontism in forensic age assessment.

Presumably taurodontic teeth were included in reference data to some extent due to their partially high prevalence in the past, whereby the influence of taurodontism has been statistically absorbed within the overall spread of the features. Future studies should compare the temporal course of these tooth characteristics in affected and unaffected teeth.

Subsequent initiatives should focus on raising awareness among forensic dentists regarding taurodontism, necessitating in-depth exploration of the subject.

1. Introduction

Forensic age assessment in living individuals relies on specific anatomical or physiological features associated with age to estimate an individual's chronological age [1,2]. These criteria typically encompass features with replicable development stages occurring within a consistent timeframe. This methodology proves valuable when determining the legal or administrative age of an individual [1].

Various age-associated features are utilized in forensic age assessment, with the term "dental age estimation" (DAE) gaining prominence when dental characteristics are employed to deduce chronological age [3–7]. DAE is an integral component of age assessment procedure recommendations [8].

It is often the critical question of whether a person has reached the age of majority. In these cases, typically, a dental panoramic radiograph (PAN) is obtained, followed by the evaluation of the eruption and mineralization of the third molars [1]. The use of these features is rooted in the fact that third molars are generally the last teeth to develop. Given that forensic age assessment often centers around establishing whether an individual has reached the age of majority (18 years), the completion of third molar development aligns with this time frame [1,9]. The assessed third molar data is then compared with reference populations to infer the chronological age of the individual. In practical application, dental criteria are combined with skeletal development features [1,8].

Once the development of the third molars, and consequently, the entire dentition, is finalized, attention turns to analyzing degenerative

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tooth characteristics. Examining age-associated degenerative tooth features involves assessing the radiographic visibility of root canals and the visibility of the periodontal ligament in mandibular third molars, for instance [10–15].

The distinctive suitability of developmental features, particularly those related to tooth development, for forensic age assessment stems from their genetic determination, rendering them minimally influenced by external factors [16,17]. To exemplify the precision of genetic control in development, one can refer to the temporal sequences of embryogenesis. Despite the substantial independence of tooth development from external factors in a physiological context, diseases can exert an influence. Indeed, diseases may alter tooth development, posing a risk in forensic age assessment as pathologically affected teeth can lose their association with chronological age. Consequently, deducing chronological age from such teeth can become unfeasible. The significance of this issue intensifies when the disease involved is genetically determined due to the genetic dependency inherent in tooth development [16,18].

In contrast, evaluating degenerative features poses a challenge as they lack genetic determination [19,20]. The transition from age-associated physiological degeneration to pathology occurs gradually. Thus, it is imperative to meticulously assess each individual case to determine whether a condition is pathological.

The examination of the effect of specific diseases or conditions on dental age has recently emerged as a focal point in the field of age assessment research [21–25]. Current deliberations generally suggest that diseases causing developmental delays result in a less consequential distortion of age estimates [1,8]. Individuals affected by such conditions would typically be appraised as younger, a circumstance that usually does not entail significant drawbacks for them. However, including individuals with no adverse effects into reference populations poses a substantial risk to the validity of age estimates derived from such data.

In specific instances, an overestimation of age becomes particularly problematic, potentially having direct negative repercussions on the individuals being assessed [1,26]. Hence, diseases causing accelerated development necessitate careful exclusion. Precocious puberty, adrenogenital syndrome, and hyperthyroidism are notably regarded as particularly problematic, especially concerning skeletal age. In contrast, their influence on dental age seems either absent or weak [1].

Analysis of data revealed that age assessment is rendered impossible in approximately 1% of cases due to medical conditions that accelerate development, with hyperthyroidism being the predominant cause [1]. This underscores the critical need for discernment and caution in including individuals with such conditions in age assessment studies, emphasizing the potential effect on accuracy and reliability.

Exploring the influence of dental alterations provides insight into the phenomenon known as taurodontism, a morphological deviation in tooth structure. Currently, the question of how taurodontism affects both developmental and degenerative dental criteria remains unanswered. Specifically, the suitability of taurodontic teeth for forensic age assessment remains an unresolved inquiry.

This article aims to present the current state of knowledge on taurodontism and underscore its relevance within the field of forensic age assessment. A literature synthesis of existing literature associating taurodontism with forensic age assessment was conducted. Additionally, this article delves into the potential influence of taurodontism on established criteria related to the development and degeneration of third molars. Ultimately, the research gap in the domain of taurodontism and DAE will be explored, outlining the need for future studies.

2. Taurodontism

Taurodontism denotes a morpho-anatomical alteration in the tooth structure characterized by an expansion of the tooth body and a reduction in root length (Figs. 1 and 2) [27]. Hence, taurodontism represents a persistent anatomical aberration observed in both permanent and primary posterior dentition, characterized by an expansion of the pulp chamber resulting from an apical shift in the root furcation, with consequent reduction of the root branch [28]. Alternative definitions explicitly highlight the exclusive involvement of molars [29]. Still others see a reference to multi-rooted teeth [30]. The alteration is associated with a deficiency or retardation in the invagination process of Hertwig's epithelial sheath, leading to an atypical horizontal positioning of the impending root furcation [28]. The bifurcation may be situated merely a few millimeters proximal to the apical regions of the roots [31].

Fig. 1. Cropped panoramic radiograph showing the typical apical displacement of the root bifurcation seen in Taurodontic teeth 37 [FDI] and 38.

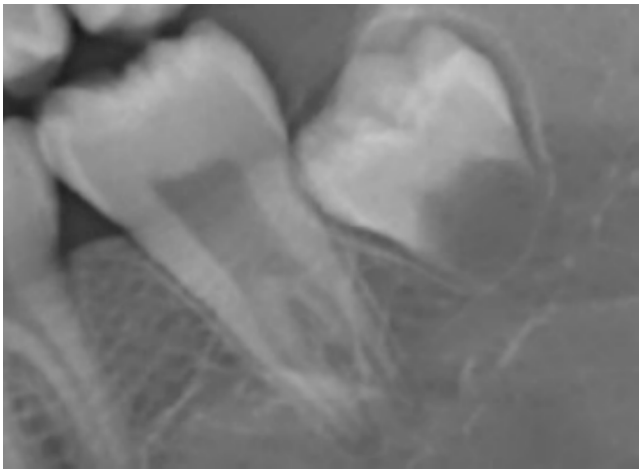

Fig. 2. Cropped panoramic radiograph showing a taurodontic tooth 37 [FDI] and developing 38. These cases are challenges for forensic age assessment as the developmental behavior of tooth 38 cannot be reliably classified today.

Over the years, a variety of different definitions and classifications for taurodontism have been published. A definition by Shifman and Chanannel from 1978 is generally practicable. The two authors defined a distance > 2.5 mm between the cemento-enamel junction (CEJ) and the pulp floor as the presence of taurodontism. Tulensano et al. increased this distance definition to 3.5 mm in 1989. Feichtinger and Rossiwall in 1977 came up with a definition that uses a ratio instead of absolute values. Feichtinger and Rossiwall asserted that, for a taurodontic tooth, the distance from the bifurcation or trifurcation of the root to the CEJ should exceed the occluso-cervical distance [31].

The specific appearance of the affected teeth has also given the alteration its name. Sir Arthur Keith initially introduced the term "taurodontism" in 1913 [31]. He introduced the term derived from the

Greek words "tauros," meaning "bull," and "odontos," signifying "tooth", owing to the morphological similarity between the affected tooth and that of a hoofed animal, particularly bulls [31].

The severity of taurodontism can be described with the help of specific indices of various authors [32]. As a rule, the size of the pulp chamber is set in relation to the rest of the tooth. Depending on the index measured, a distinction is made between cynodont, hypo-, meso- and hyper-taurodont. Hyper-taurodont is the most severe form with only minimal remaining roots [33].

With regard to DAE, the question arises as to the severity of taurodontism to be taken into account in forensic practice. Certainly, special handling is likely necessary for severe forms.

For hypo-taurodontism as a borderline form, however, it should be clarified in the future how appropriately altered teeth should be handled in forensic practice.

Presently, the aetiology of taurodontism remains unclear; however, several hypotheses have been postulated, including a genetic basis involving the Wnt10A gene, pathogenic variants in KIF4A leading to missense, developmental anomalies, or potential syndromic associations [28,34]. Some authors have linked taurodontism to novel ITGB6 variants and reduced ITGB6 expression [35]. Other authors consider taurodontism to have a multifactorial aetiology. They see genetic changes together with heavy masticatory habits as causing the dental alterations [32]. In the past, taurodontism has also been reported in the literature to be associated with radiation therapy [36,37].

Today, it is assumed that taurodontism as such has no particular pathological value. On the other hand, taurodontism is associated with certain syndromes that can present a pathological value [33,38]. In fact, such a strong association was found that taurodontism was hitherto considered to be a marker of oro-facial disorders [33]. Overall, taurodontism can pose a significant challenge for the dentist if dental treatment is required. Root canal treatment and extractions in general can be particularly complex [39].

The prevalence of taurodontism in different populations has been well investigated. For example, prevalences of about 2 percent have been described for Germany [40], while in Senegal, for example, up to 48 percent have been reported [41]. For a Chinese cohort, a prevalence of 46% was found, although a very recent study found a prevalence of 29% in a Chinese population [28,42,43]. In a Brazilian population, Weckwerth et al. found a prevalence of 43% [44]. In a *meta*-analysis that included 15 studies and a total of 14,771 individuals, Decaup et al. found an overall prevalence of taurodontism of 11.8% across different populations in 2022 [28]. An example of a very low prevalence is provided by Patil et al. with 0.4% in a North Indian population. A sex difference is not currently assumed [30,32].

In view of the high prevalence of taurodontism in certain normal populations, it has recently been asked to what extent taurodontism can still be a marker for pathologies [33]. Since taurodontic teeth have also been found in the remains of Homo neanderthalensis, it can rather be asked whether taurodontism is in fact a "typical human variant" [28]. Against this background, the question of the influence of taurodontism on DAE almost inevitably arises.

Given the prevalence, reaching up to 50% in certain populations, it is plausible that taurodontic teeth were encompassed in previous reference studies on DAE in the past. It can therefore reasonably be inferred that the phenomenon has so far been statistically reflected in the overall spread of trait expression in the relevant studies. It is therefore not possible to determine with certainty whether taurodontism has an effect on tooth development or whether taurodontic teeth develop faster or slower than unaffected, healthy teeth. The following sections deal with the current state of knowledge on the effect of taurodontism on some of the established features of DAE.

3. Third molar eruption

The assessment of the eruption of mandibular third molars using PAN radiographs is an established and evidence-based method for forensic age assessment [45–52]. Various staging scales are available in the literature to assess this feature [53]. Regardless of the staging scale, the eruption is classified according to the physiological stages [54] and assessed according to the expression in corresponding reference populations. It should be emphasized that eruption, as a determinant in forensic age assessment, remains applicable to taurodontic teeth across all known staging scales (Figs. 1 and 2).

The effect of taurodontism on the chronological sequence of mandibular third molar eruption is currently poorly understood.

A fundamental challenge arises from the fact that eruption can be assessed in teeth at an early stage of mineralization, at which point it may be difficult to determine whether the tooth is taurodontic. This inherent challenge heightens the risk of inadvertently examining affected teeth without awareness. Consequently, there is a need to be vigilant for taurodontism in other coexisting teeth. While the primary emergence of this alteration is frequently observed in permanent molars, it is noteworthy that such changes can manifest in both permanent and deciduous dentition [32]. Moreover, these alterations may occur unilaterally or bilaterally and can involve any combination of teeth or quadrants [32]. Some authors even assume that if a person is affected by taurodontism, all three molars are always affected. The severity then increases from anterior to posterior [30,33].

Therefore, in the case of partially developed third molars, it is advisable to use the first and second molars as an indicator of taurodontism in DAE procedures.

Another significant concern is the potential association of taurodontism with syndromes that may disrupt the normal time frame of physiological tooth development or skeletal development [32,55–57]. The literature refers to over 20 syndromes associated with taurodontism [30,31]. Syndromes that are associated with taurodontism and at the same time influence tooth development include Ellis van Creveld syndrome, Kabuki syndrome, Apert syndrome, Wolf-Hirschhorn syndrome, Lowe syndrome and Klinefelter syndrome, to name but a few [32].

Wolf-Hirschhorn syndrome is also known to be associated with retarded growth [32]. Therefore, the presence of taurodontism in an age assessment examination may indicate the presence of a disease or syndrome that affects skeletal development. This emphasizes the relevance of taurodontism in forensic age assessment beyond just dental criteria.

4. Third molar mineralization

The evaluation of the mineralization of mandibular third molars in PAN radiographs is regarded as the essential feature of DAE [1,22,58–61]. This is since forensic age assessment is often concerned with proving a possible age of majority and the completion of the development of the third molars falls within this age period. The influence of taurodontism on the mineralization of the third molars is unknown.

Remarkably, in 1996 Tompkins addressed the assessment of the mineralization of taurodontic molars [62]. Tompkins realized that the staging scale established by Demirjian et al. in 1973 [59] was unsuitable for taurodontic teeth. Tompkins then presented a modification of the staging scale by Demirjian et al. that would allow affected teeth to be assessed [62]. This shows that the well-known and established staging scales of Demirjian et al. and its modification by Mincer et al. from 1993 [63], in which certain morphological phases are assigned to the developmental stages, are fundamentally unsuitable for evaluating taurodontic teeth. For example, in these staging scales, the development of the root bifurcation is decisive for the assignment of a specific stage. On the other hand, the assignment of another stage requires that the root length exceeds the crown height. It is obvious that these criteria cannot be applied without systematic error when assessing taurodontic teeth.

Another common method for DAE on third molars is the determination of the third molar maturity index $I_{3M,}$ according to Cameriere et al. [64]. This method can even be used in principle for taurodontic

teeth. However, it must be stated that the method would probably deliver incorrect results in these cases. This can be presumed as this method evaluates the entire opening of the tooth germ apically as an apex opening until the formation of two roots with one apex each [64]. It is evident that this one wide opening is significantly longer in taurodontic teeth, which would lead to incorrect evaluations.

Even with certain atlas methods for DAE, no taurodontic teeth can be seen in the illustrations, so technically correct application of this method is not possible for these cases [9].

Overall, it can be concluded that all methods or classifications that use the mineralization of the third molars for the purpose of forensic age assessment are influenced by taurodontism. Either the classification is technically not applicable correctly, or the results are not reliable due to the undetermined influence of taurodontism on the feature.

5. Visibility of root canals in third molars

The evaluation of mandibular third molar root canal visibility in PAN radiographs constitutes an evidence-based criterion for dental age estimation (DAE) following the completion of tooth development [10,15,65,66]. With advancing age, there is a gradual reduction in the radiological visibility of root canals, yet the precise aetiology of this initially purely radiomorphological phenomenon remains unclear. It is hypothesized that various age-related processes in both the tooth and the surrounding tissues contribute to this phenomenon. This feature is determined in teeth with completed development, facilitating the identification of taurodontism presence or absence during the assessment.

Concerning taurodontism, it is evident that teeth affected by this condition, especially in severe forms, cannot be adequately evaluated as the roots are only minimally present. Given that taurodontism stems from the maldevelopment of the Hertwig epithelial sheath responsible for root development, it cannot be confidently assumed that the processes leading to the reduction of root canal visibility occur similarly to affected and unaffected teeth.

Consequently, it can be concluded that the evaluation of this feature lacks meaningful feasibility in severe forms of taurodontism. Even if an assessment is theoretically possible, the influence of taurodontism on the feature remains uncertain.

6. Visibility of periodontal ligament space in third molars

The appropriateness of evaluating the visibility of the periodontal ligament space surrounding mandibular third molars in PAN radiographs has been widely acknowledged [10,11,65,67–69]. Analogous to the appraisal of root canal visibility, the underlying physiological basis for this radiological phenomenon remains incompletely elucidated. In this context, it is postulated that the aetiology involves a complex interplay of various age-related degenerative processes. This feature is also evaluated in fully mineralized teeth.

The lack of clarity about the influence of taurodontism on the degenerative features stems from a lack of research on the subject. Furthermore, it is imperative to consider that some staging scales for this feature incorporate the assessment of the periodontal ligament between the roots. It is evident that distortions may arise in cases of taurodontism characterized by exceptionally shortened roots. Hence, it is particularly intriguing to observe that Guo et al. have introduced a staging scale wherein the region between the roots is not considered in 2020. Rather, the evaluation focuses solely on the mesial and distal periodontal ligaments of the tooth [70]. While Guo et al. do not explicitly reference taurodontism, considering its reported prevalence in China nearing 30%, it is plausible that this factor might have played a role in development of their staging scale. Future studies should examine whether the staging scale by Guo et al. from 2020 [70] is suitable for evaluating the characteristic of the visibility of periodontal ligament on taurodontic mandibular molars.

7. Future research

In future studies, some pending issues regarding taurodontism and forensic age estimation need to be clarified. To start, there is a need to clarify the stage of severity of taurodontism at which it is relevant for forensic age assessment.

Furthermore, comparative studies for eruption and mineralization of mandibular third molars should be performed for normal teeth and taurodontic teeth (Fig. 2). The challenge for such a study design will be that taurodontism is not reliably detectable in the early stages of the traits, which is why a control would be necessary at a later stage. This control would then have to verify whether the tooth included as a taurodontic tooth at a low stage of development is indeed affected by taurodontism.

In addition to the developmental characteristics of DAE, the influence of taurodontism on the degenerative tooth features should also be investigated through high-quality studies. The influence of taurodontism on age estimation in general should thus be characterized and quantified.

In addition, new staging scales should be developed for high-prevelance areas, which can be applied to taurodontic teeth without skewing the results.

8. Conclusions

The high prevalence of up to almost 50% in some populations underlines the relevance of taurodontism for forensic age assessment.

The influence of taurodontism on the common features of DAE is currently elusive and urgently needs to be investigated. To this end, future studies should compare the temporal course of these tooth characteristics in affected and unaffected teeth.

As some of the staging scales for the features cannot be applied appropriately to taurodontic teeth, there may be a need for modified staging scales for high-prevalence regions.

Since taurodontism can also be an indicator of syndromes altering skeletal development, there is a relevance for forensic age assessment beyond dental criteria.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

No new data were created or analyzed in this study. Data sharing is not applicable to this article.

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