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Research article

Prevalence of taurodontism in individuals in Northwest China determined by cone-beam computed tomography images

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ABSTRACT

Objective: The aim of this retrospective study was to evaluate the prevalence of taurodontism in a group of adult dental patients in Northwest China with the aid of cone-beam computed tomography (CBCT).

Methods: This study used Shifman and Chanannel's criteria to statistically analyze the prevalence of taurodontism in the premolars and molars of the Chinese population. CBCT images of 5488 teeth from 580 subjects of Chinese origin were evaluated. The measured data were statistically analyzed and the chi-square test was also used to compare the prevalence of taurodontism between male and female subjects and between the upper and lower jaws ($P < 0.05$).

Results: Taurodontism was detected in 169 patients, with a prevalence of 29.14%, of which 27.24% were males and 30.65% were females. The chi-square test showed that there was no significant difference between males and females ($P > 0.05$). Taurodontism was found in 7.45% of all teeth examined. Taurodonts were significantly more common in the maxilla (9.06%) than in the mandible (5.15%) ($P < 0.001$), and the maxillary second molar (25.18%) was the most common tooth affected. According to morphology, hypotaurodonts were the most common (60.39%) among taurodontic teeth.

Conclusions: Taurodontism was relatively common in the Chinese population and was almost equally distributed between males and females. The maxillary second molar was the most common tooth of all taurodonts measured, and taurodonts were significantly more common in the maxilla than in the mandible. Hypotaurodontism was the most common form of taurodontism. Our study provides a reference for dental deformities in the Chinese population and the diagnosis and treatment of taurodontism.

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1. Introduction

Taurodontism is characterized by root enlargement of the pulp chamber, root bifurcation shift to the root tip, and a lack of stenosis at the level of the cementoenamel junction (CEJ) [1]. As early as 1913, Keith studied the morphology of early fossil teeth of prehistoric humans and found that some teeth had shortened roots and enlarged pulp chambers. This form of tooth is usually found in ungulate animals or mammals that chew their food (such as cattle); hence, this guided Keith's first concept of "taurodontism" [2]. In 1928, Shaw et al. [3] classified taurodontism, including conical root teeth, as hypotaurodonts, mesotaurodonts or hypertaurodonts according to the amount of translocation from the pulp chamber floor to the root apex. However, this classification method is mainly based on the subjective evaluation of radiological images by observers, which is not highly accurate and is highly subjective [4]. Later, some scholars proposed a more objective classification method of taurodontism. In 1978, Shifman and Channel defined taurodontism as "a variation in the internal morphology of the pulp chamber, characterized by the extension of the pulp chamber to the root area". Also, these authors proposed a method for diagnosing taurodontism by measuring intraoral radiographs. Taurodontism was diagnosed when the taurodontic index (TI) exceeded 20 and the vertical distance from the CEJ to the highest point at the bottom of the pulp chamber $|BD|$ exceeded 2.5 mm. TI = $|AB|/|AC| \times 100$, where $|AB|$ is the vertical distance between the lowest point at the top of the pulp chamber and the highest point at the bottom of the pulp chamber, and $|AC|$ is the perpendicular distance between the lowest point at the top of the pulp chamber and the apex of the longest root. According to the value of the TI, taurodontism can be divided into three different degrees: $20 < TI < 30$ indicates hypotaurodontism, $30 \leq TI < 40$ indicates mesotaurodontism, and $40 \leq TI < 75$ indicates hypertaurodontism [4].

In previous studies, we found that the prevalence of taurodontism varied greatly among different ethnic groups. However, there were few studies on the prevalence of taurodontism in the Chinese population; only the 1993 survey on the prevalence of taurodontism among adolescents in Hong Kong, China, showed that taurodontism prevalence was as high as 46.4% [5]. Although taurodontism is common in China, it rarely attracts the attention of dentists in clinical practice. Previous studies mostly used intraoral X-ray and panoramic radiographs to measure the prevalence of taurodontism. However, Lo Giudice et al. [6] indicated that CBCT could provide more accurate information in the measurement of tooth anatomical structure than intraoral X-ray, which had the same conclusion as previous research [7,8].

Therefore, to overcome the limitations of two-dimensional images in previous studies and enrich the data on taurodontism in the Chinese population, this study intended to calculate the prevalence of taurodontism in Chinese adult premolars and molars by measuring CBCT data, analyze whether taurodontism is related to sex and tooth position and determine the most common degree of taurodontism in individuals in Northwest China.

2. Materials and methods

This retrospective study was approved by the Ethics Committee of The Fourth Military Medical University (IRB-REV-2021030). Patients under 18 years old and CBCT images of poor quality (distorted, elongated, or over/underexposed images) were excluded. In addition, patients with an inadequate number of teeth (less than 26 teeth), fractured teeth, third molars, teeth that had crowns, teeth
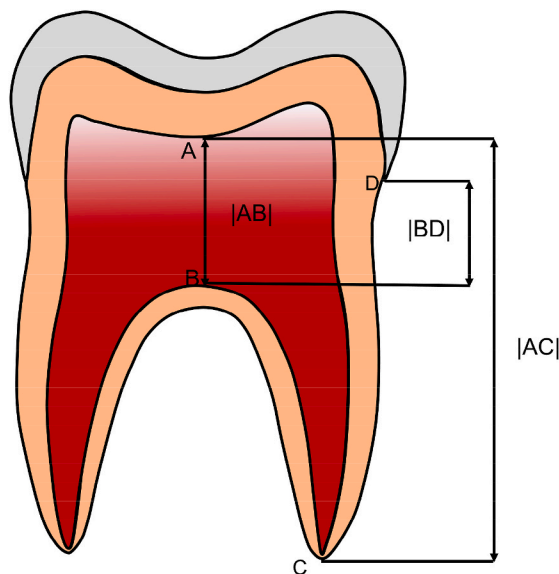
Fig. 1. Schematic diagram of tooth measurements: $|AB|$ is the vertical distance between the lowest point at the top of the pulp chamber and the highest point at the bottom of the pulp chamber; $|AC|$ is the perpendicular distance between the lowest point at the top of the pulp chamber and the apex of the longest root; $|BD|$ is the vertical distance from the CEJ to the highest point at the bottom of the pulp chamber.

that had undergone endodontic treatment, teeth with caries or restorations that influenced the diagnosis of taurodontism, teeth with incomplete apical foramen formation and teeth with undetectable furcation were not included. Only molars and premolars with two or more roots were included in this study. A sample of 50 CBCT images was remeasured by the same person approximately two weeks later, and measurements were completely consistent. The records of 580 patients attending the Department of Radiology, School of Stomatology, The Fourth Military Medical University between September 2018 and December 2020 were investigated using CBCT images for the study.

All CBCT images were taken with the same machine (HighRes3D, LargeV, Beijing, China) with the following scanning parameters: 100 kV, 4 mA, 12.5 s exposure time, and 0.25 mm pixel size. All images were viewed by one experienced oral radiologist. The original CBCT images of the patients were evaluated using LargeV's 3D imaging software (v1.2.1903.5840) in the cross-sectional, coronal and sagittal planes. According to the standard of "Shifman and Channel", we measured three variables (Fig. 1). The authors also proposed the TI, and taurodontism was diagnosed when the TI exceeded 20 and |BD| exceeded 2.5 mm. According to the value of the TI, taurodontism can be divided into three different degrees: $20 < TI < 30$ indicates hypotaurodontism, $30 \leq TI < 40$ indicates mesotaurodontism, and $40 \leq TI < 75$ indicates hypertaurodontism [4]. Three degrees of premolars and molars were shown in Figs. 2 and 3.

(1) Determination of the measurement direction: The longitudinal axis is adjusted so that it is parallel to the long axis of the tooth under the sagittal and coronal planes.
(2) Determination of the survey point: (A) The lowest point of the parietal pulp chamber is the point where the first high-density image disappears in the pulp chamber. (B) The highest point of the pulp floor is the point where a high-density image is about to appear again in the pulp chamber. (C) The apex of the longest root is the point at which the high-density image of the apex of the longest tooth disappears for the first time. (D) The point where the high density of enamel around the tooth disappears for the first time.
(3) Measurement accuracy: The vertical distance of the above marked points was measured, measurements could be recorded at two decimal points, and all the measurements and analyses were completed by an examiner in continuous time.

Statistical analysis of data was implemented using Statistical Product and Service Solutions 26.0, and the frequency distribution for taurodontism was calculated. The chi-square test was used to compare the prevalence of taurodontism between male and female subjects and between the upper and lower jaws ($P < 0.05$).

3. Results

The study group comprised 323 (55.69%) females and 257 (44.31%) males with a mean age of 33.9 years. The age range was 18–67 years. Tables 1 and 2 show that for the 580 patients, 169 (29.14%) had one or more teeth that were taurodonts. Of the 5488 teeth examined, each with two or more roots, 409 (7.45%) teeth were found to have taurodontism. Maxillary second molars were the most
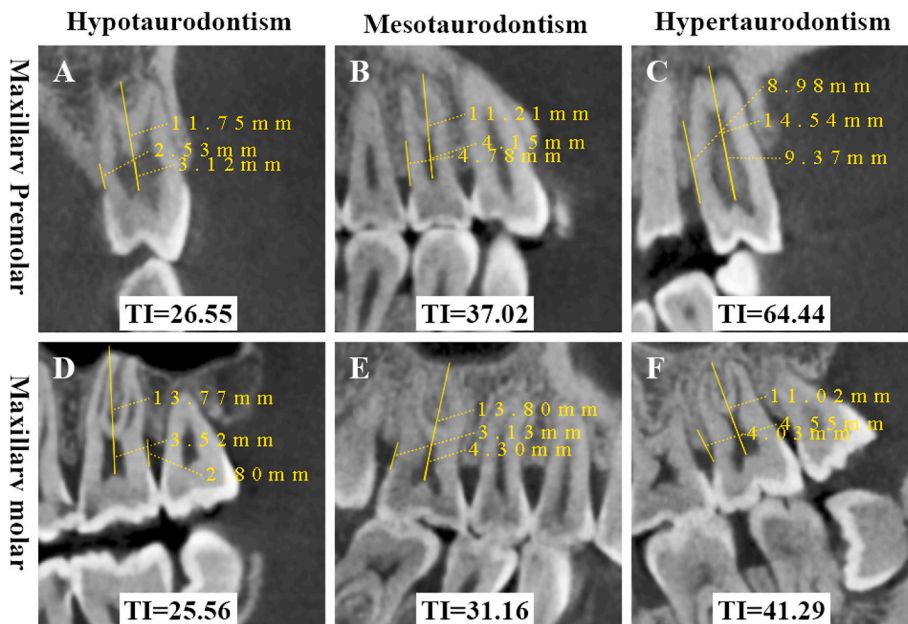

Fig. 2. Hypotaurodontism, mesotaurodontism and hypertaurodontism for maxillary premolars and molars. Hypotaurodontism in maxillary premolars (A). Mesotaurodontism in maxillary premolars (B). Hypertaurodontism in maxillary premolars (C). Hypotaurodontism in maxillary molars (D). Mesotaurodontism in maxillary molars (E). Hypertaurodontism in maxillary molars (F).
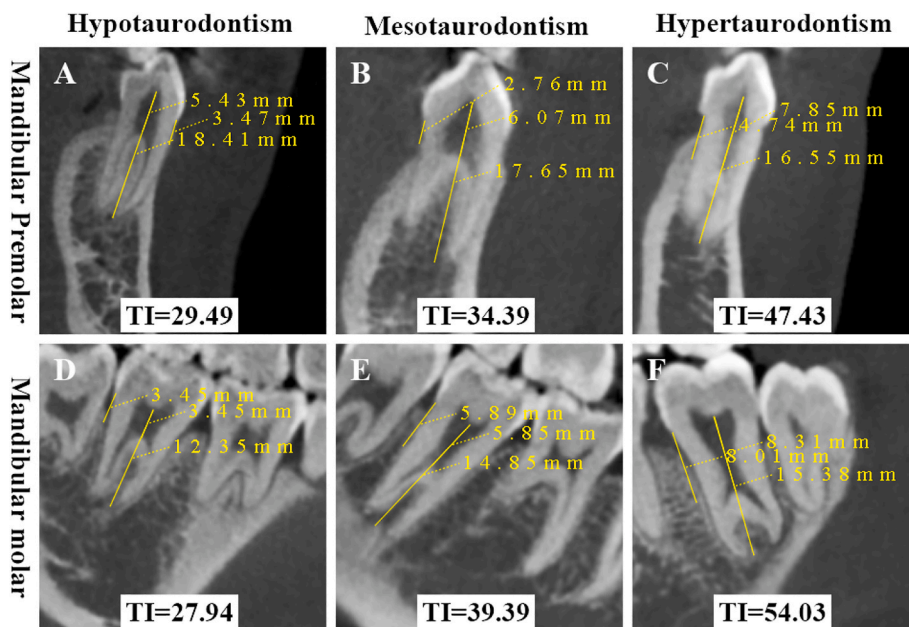
Fig. 3. Hypotaurodontism, mesotaurodontism and hypertaurodontism for mandibular premolars and molars. Hypotaurodontism in mandibular premolars (A). Mesotaurodontism in mandibular premolars (B). Hypertaurodontism in mandibular premolars (C). Hypotaurodontism in mandibular molars (D). Mesotaurodontism in mandibular molars (E). Hypertaurodontism in mandibular molars (F).

Table 1
Distribution of taurodontic teeth among 5488 teeth in the maxilla and mandible categorized by tooth type.

Tooth type	Maxilla		Mandible		Total	
	NTE	TDP	NTE	TDP	NTE	TDP
First premolar	839	96	86	77	925	173
Second premolar	194	41	1	1	195	42
First molar	1130	53	1093	0	2223	53
Second molar	1071	103	1074	38	2145	141
Total	3234	293	2254	116	5488	409

NTE: Number of teeth examined.
TDP: Taurodonts present.

Table 2
Distribution of taurodontic teeth among 580 patients categorized by the patients' sex.

Sex	Taurodontic teeth		Nontaurodontic teeth		Total	
	NO.	%	NO.	%	NO.	%
Male	70	12%	187	32%	257	44%
Female	99	17%	224	39%	323	56%
Total	169	29%	411	71%	580	100%

Table 3
Distribution of three different degrees of 409 taurodontic teeth.

Tooth Type	Hypotaurodontism		Mesotaurodontism		Hypertaurodontism		Total	
	NO.	%	NO.	%	NO.	%	NO.	%
First premolar	65	15.89%	56	13.69%	52	12.71%	173	42.30%
Second premolar	21	5.13%	16	3.91%	5	1.22%	42	10.27%
First molar	47	11.49%	6	1.47%	0	0.00%	53	12.96%
Second molar	114	27.87%	23	5.62%	4	0.98%	141	34.47%
Total	247	60.39%	101	24.69%	61	14.91%	409	100.00%

common taurodonts of all teeth measured (25.18%). The distribution of taurodontic teeth among the 5488 teeth assessed in the maxilla and mandible is shown in Table 1. Analysis of total taurodonts in the mandible (5.15%) versus maxilla (9.06%) showed a statistically significant difference ($\chi^2 = 29.50$, $P < 0.001$), and the prevalence of taurodontism in the maxilla was higher than that in the mandible.

The distribution of taurodontic teeth among 580 patients by sex is shown in Table 2. Taurodontism was present in 70 of the 257 male patients (27.24%) and 99 of the 323 female patients (30.65%). The sex distribution of the patients with taurodontism showed no statistically significant difference ($\chi^2 = 0.81$, $P > 0.05$).

Regardless of the type of tooth, hypotaurodontism was the most common degree of taurodontism. Also, a large proportion of second molars had hypotaurodontism whereas a large proportion of first premolars had mesotaurodontism and hypertaurodontism (Table 3).

4. Discussion

The etiology of taurodontism has not been fully clarified, and it is generally considered to involve multiple factors, including genetic variation, hereditary factors, environmental factors and changes in hormone levels. Current theories concerning the etiology of taurodontism tend to be commonly attributed to an alteration in Hertwig's epithelial root sheath [9]. Taurodontism may occur when the rupture of the Hertwig epithelial root sheath is delayed or the Hertwig epithelial root sheath breaks at an inappropriate level [10]. In other opinions, taurodontism may be related to an increase in the number of X chromosomes (The more the number of extra X chromosomes, the more severe the taurodontism will be. eg, 48,XXXY) [11]. Many findings suggested that a loss of Wnt10a function would lead to the occurrence of taurodontism [10,12–14]. Although commonly seen as an isolated trait, hereditary factors also play a certain role in the occurrence of taurodontism. There were occasional reports that taurodontism may be associated with several syndromes, such as trichodento-osseous syndrome (TDO) [15], echodactyly ectodermal dysplasia-cleft lip/palate (EEC), ankyloblepharon-ectodermal defects-cleft lip/palate (AEC) [16], Klinefelter's syndrome [17] and laurence-moon-Bardet-biedl syndrome (LM/BBS) [18]. This means that dentists may be the first to discover these systemic syndromes. Therefore, it is necessary for dentists to have a good understanding of taurodontism because it may be a valuable clue that could be used to discover the condition of the patient's systemic syndrome.

To better compare the prevalence of taurodontism in the Chinese population with that in other ethnic groups, this study used Shifman and Chanannel's criteria, which have been commonly used in recent studies, to statistically analyze the prevalence of taurodontism in the premolars and molars of the Chinese population. This study excluded third molars because third molars have larger variations among different populations [19]. In addition, the third molars may be removed due to neoplastic, infectious, inflammatory, iatrogenic, cystic and other conditions [20]. Premolars were added to this study and were excluded by some studies [21, 22] because premolars (except the first maxillary premolar) usually do not have more root bifurcations and are thought to have a small chance of taurodontism (0.79%) [23]. In fact, we observed by CBCT that many premolars (24.14%) also have buccal-lingual root bifurcations; this outcome cannot be observed in two-dimensional images.

This study found that the prevalence of taurodontism was 29.14% for individuals and 7.45% for teeth, which is lower than the results (46.4% for individuals and 21.7% for teeth) of MacDonald-Jankowski and Li [5]. The reasons for the difference may be that, first of all, the diagnostic criteria of the two studies are different. The previous study only judged taurodontism by the value of variable |BD|, whereas this study combined TI with variable |BD| to determine taurodontism. Taurodontism was diagnosed only when the two conditions were met simultaneously. Furthermore, the patients selected in this study were adults, rather than young Chinese people aged 15–19 years old who did not have a completely formed root apex. With increasing age, secondary dentin deposition gradually reduces the pulp chamber [24], which may make some teeth less likely to be diagnosed with taurodontism. Finally, CBCT images were used in this study to measure teeth in three-dimensions, and premolars were also included in this study. Therefore, compared with the prevalence of taurodontism, which includes only molars, the prevalence of taurodontism, including premolars and molars, may change greatly. Previous studies revealed that the prevalence of taurodontism varied greatly among different races and countries. The prevalence of taurodontism was reported to be 0.1% in western Saudi Arabia by subjective radiographic evaluation [25], 0.26% in the Anatolia population by measuring the distance from the root bifurcation to the CEJ [26], 5.5% in southern Iran by Blumberg Index [27] and 11.28% in Trinidad and Tobago by subjective radiographic evaluation [28]. The prevalence of taurodontism was 42.8% in Brazil by the Shifman and Channel's criteria [29], which was extremely high. The extensive variation in different studies may be due to ethnic differences, different diagnostic criteria of taurodontism, and the inconsistency of the specific teeth examined.

The present data indicated that maxillary second molars were the most common of all taurodonts measured, which was the same as the results reported in some studies [5,30]. However, some studies suggested that mandibular second molars were the most common teeth to exhibit taurodontism [4,26,27]. The difference may be explained primarily by the racial and regional variations, differences in sample selection and the differences in criteria used for interpretation of taurodontism and also the specific teeth examined. For example, in some studies (such as the present one), including premolars, excluding third molars [19], and reporting prevalence based on the number of teeth and patients with taurodontism may also be an important factor affecting the results [29]. In addition, compared with two-dimensional images, three-dimensional CBCT used in our study can measure root canal anatomy and the pulp chamber height in parasagittal sections with minimal distortion [6]. Furthermore, of the 5488 teeth examined in the present study, 7.45% were taurodonts. Moreover, the higher prevalence of taurodontism in maxillary teeth compared to mandibular teeth (9.06% vs. 5.15%) is in accordance with the data released by Trinidad [28]. This study showed that there was no significant difference in the prevalence of taurodontism between men and women, which was similar to the findings of previous studies [4,26,30,31]. Nevertheless, in other studies [5,27], a higher prevalence of taurodontism was found in females, which may be associated with specificities within each race and region or the difference in the number of research participants. The results of this study show that the most common morphological type of taurodontism is hypotaurodontism, which is similar to the results of previous studies [4,27,30,32].

In conclusion, the findings of this study showed that taurodontism was relatively common in the Chinese population and had no difference in prevalence based on sex. The maxillary second molar was the most common of all taurodonts measured, and taurodonts were significantly more common in the maxilla than that in the mandible. Also, hypotaurodontism was the most common type of taurodontism. Dental treatments of such taurodontic teeth are challenging because of the special morphology that these teeth exhibit [33–35]. The results of this study could provide clinicians with more anatomical knowledge of taurodontism so that they could accurately diagnose and treat taurodontism in clinical practice. The clinicians should realize that neglecting this anatomical variation may influence the clinical treatment outcomes. However, one limitation of this study was the inability to evaluate the correlation of familial and genetical background. Assessing the relationship between the incidence of taurodontism and genetic diseases may provide a valuable clue for clinicians to detect any associated syndromes and other conditions. Another limitation was that we only surveyed the population in northwest China, and the present results should be considered with caution as it may not be representative for the overall Chinese population. Nonetheless the findings form a basis for further studies. More studies on the prevalence of taurodontism should be carried out in a wider population, and long-term follow-up studies regarding treatment of taurodont teeth should be conducted in the future. In addition, more investigations are recommended to assess the correlation between taurodontism and genetical background, as well as the relationship between taurodontism and different syndromes.

Author contribution statement

Yujiao Li; Fei Qian: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Dan Wang; Yirong Wang: Contributed reagents, materials, analysis tools or data.

Wei Wang: Performed the experiments; Analyzed and interpreted the data.

Yu Tian: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data.

Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

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