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Taurodontic teeth in cone beam computed tomography: pictorial review

Authors:
Fourneau E MD, DDS[1,*],
Olszewski R DDS, MD, PhD, DrSc, Prof[1,2]

Affiliations:

[1] Department of oral and maxillofacial surgery, Cliniques universitaires saint Luc, UCLouvain, Av. Hippocrate 10, 1200 Brussels, Belgium
[2] OMFS Lab, NMSK, IREC, UCLouvain, Oral and maxillofacial surgery research Lab (OMFS Lab), NMSK, Institut de recherche expérimentale et clinique (IREC), UCLouvain, Brussels, Belgium
*Corresponding author: Corresponding author: Prof Raphael Olszewski, Department of oral and maxillo-facial surgery, Cliniques universitaires Saint Luc, UCLouvain, Av.Hippocrate10, 1200 Brussels, Belgium, email: Raphael.olszewski@saintluc.uclouvain.be
ORCIDID: orcid.org/0000-0002-2211-7731
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Abstract

Objective: Taurodontism is a developmental disorder with enlargement of the body of the tooth and lack of cervical constriction, which results in a large pulp chamber and small roots with the apical displacement of furcation. Taurodontism exists in deciduous, and definitive unilateral, and bilateral teeth. We found that taurodontism was also described in 67 syndromes. We proposed a review of the open access literature on taurodontism, a new clinical classification of taurodontic teeth with illustrations from free open access literature, and from our case serie of 15 patients.

Material and methods: We performed a systematic search for articles with free full text about taurodontism. The search was performed by one observer in PubMed database. We found 168 articles, and after application of inclusion/exclusion criteria we finally selected 136 articles for the review.

Results: we provided 34 figures of taurodontic teeth related to: 1) Unilateral mandibular first premolar, 2) Unilateral mandibular second premolar, 3) Bilateral mandibular first and second premolar, 4) Bilateral upper maxillary first premolars, 5) Bilateral mandibular second molars, 6) Bilateral upper maxillary second premolar and left first molar, 7) Bilateral upper maxillary third molars, 8) Bilateral upper maxillary first and second molars, 9) Bilateral upper maxillary first, second, and third molars, 10) Bilateral upper maxillary molars (third molars, second, and first left upper molars), and mandibular molars (first right, and left mandibular molars, right third molar), 11) Bilateral upper maxillary molars (first, second, third right, and left upper molars), and mandibular molars, 12) Unilateral first mandibular premolar with cleft, 13) Bilateral molars of the mandible and the upper maxilla (adolescent patient who received chemotherapy at the age of 3-years-old to treat retinoblastoma), 14) Unilateral first maxillary molar (Treacher-Collins syndrome).

Conclusions: We proposed a new clinical classification of taurodontic teeth based on hypo-, meso-, and hypertaurodontism, and on different types of deciduous, and definitive teeth (42 boxes). We were first to provide free reference images for: 1) upper maxillary second premolar hypertaurodontism, 2) mandibular second premolar mesotaurodontism, 3) upper maxillary third molar meso-and hypertaurodontism, 4) mandibular first molar hypotaurodontism, 5) mandibular third molar mesotaurodontism. We were also first to freely illustrate taurodontism related with chemotherapy, cleft palate patients, and Treacher-Collins syndrome.

Keywords: taurodontism, CBCT, cone beam computed tomography, taurodontic teeth

Introduction

Taurodontism is a dental anomaly most seen in molars. This developmental disorder contains enlargement of the body of the tooth and lack of cervical constriction, which results in a large pulp chamber and small roots with the apical displacement of furcation [1-13]. This altered crown root ratio, changes the shape of human molars from their classical "cynodont" shape (long crowns and roots but short bodies [14] to a cylindrical taurodont shape.

De Terra was the first to describe it in prehistoric men [15], then it was first described by Gorjanovic-Kramberger (1908) in a 70,000-year-old pre-neanderthal fossil, discovered in Kaprina, Croatia [13, 16-19]. The term "taurodont" was first used by Keith to describe the teeth of prehistoric Neanderthal people [1, 4, 6, 7, 9, 14, 18, 19, 20-28].

This form of tooth was found in ungulate animals or mammals that chew their food (such as cattle) [16, 25, 28]. The word taurodont is derived from the Greek word "tauros" and "odontos" which means bull and teeth respectively [1, 3, 7, 9, 18, 14, 24-26, 28]. Hence, the literal meaning of this term is "bull-shaped teeth" [1, 25, 26, 29]. For a time, taurodontism was believed to be non-existent in modern population [14, 27, 28], and later considered as a marker of orofacial abnormalities. In fact, those kinds of teeth are also found in normal individuals almost exclusively in deciduous molars [17, 18, 26, 28, 30-33], and permanent premolars [22, 24, 34-37] and molars [6, 17, 28, 31, 38-42] such as first maxillary molar [4, 6, 39, 42, 43], second maxillary molar [15, 40, 42], third maxillary molar [40], second deciduous mandibular molar], mandibular molars [44, 45], first mandibular molar [15, 19, 38, 39, 41, 43, 46], second mandibular molar [17, 19, 40, 47], third mandibular molar [40] with significantly higher prevalence in second maxillary permanent molars [1, 40]. Taurodontism was also described in permanent canines [48].

Moreover, taurodontism can both involve in one single tooth or in multiple teeth [9, 15, 27, 31, 32, 39], with unilateral or bilateral distribution [6, 9, 10, 17, 19, 22, 27, 31, 32, 39]. Given that in the mouth taurodont appears as a normal tooth with a normal crown [9, 28, 46, 49, 50], it is the radiographic features (rectangular pulp chamber [16], elongated body, short roots, apical furcation) [6] that predominates in its diagnosis [9, 44, 49, 50]. Bitewing radiography, periapical radiography [4, 6, 9, 10, 28, 32, 34], panoramic [5, 9, 10, 14, 16, 21, 24=18a, 29, 38, 49, 51-56] or CBCT [1, 15, 22, 25, 27, 37, 57-59, 60] can be used as diagnostic imaging for taurodontism. However, two-dimension (2D) techniques are less accurate than a three-dimensional (3D) imaging technique for tooth and root measurements. CBCT [1, 15, 22, 25, 27, 35, 36, 57, 59, 60-62] is helpful in prevalence studies, diagnosis, classification, accurate measurement and in the endodontic treatment of taurodontism and should be considered as the gold standard in aiding diagnosis and assisting in endodontic treatment [1].

In 1928 Shaw was the first to introduce a classification for taurodontic teeth as mild (hypotaurodontism), moderate (mesotaurodontism) or severe (hypertaurodontism) according to their amount of displacement of the floor of the pulp chamber [3, 6, 9, 13, 15, 19, 25, 27-29, 32, 63-65]. The taurodontic index proposed by Shifman and Chanannel in 1978 [4, 9, 13, 19, 21, 28, 66] is the most frequently used classification [21] because this system eliminates the individual interpretation and give objective evaluation points. The taurodontism index of Shifman and Chanannel, is calculated by a standardized formula (Figure 1):

Taurodontism index: $TI = \frac{a}{b}\, x\, 100$

(a) Variable 1 = the vertical height of the pulp chamber = the distance between the lowest point of the roof of the pulp chamber and the highest point in the floor of the pulp chamber.
(b) Variable 2 = the distance between the lowest point of the roof of the pulp chamber and the apex of the longest root

Variable 3 = the distance between the baseline connecting the two cementoenamel junctions and the highest point in the floor of the pulp chamber.

In this way, Shifman and Chanannel criteria to identify taurodont is a TI above 20 and variable 3 superior of 2,5mm. The tooth is classified as hypotaurodontism (TI 20-30%), mesotaurodontism (TI 30-40%) and hypertaurodontism (TI 40-75%) [13, 15, 16, 19, 25, 32].

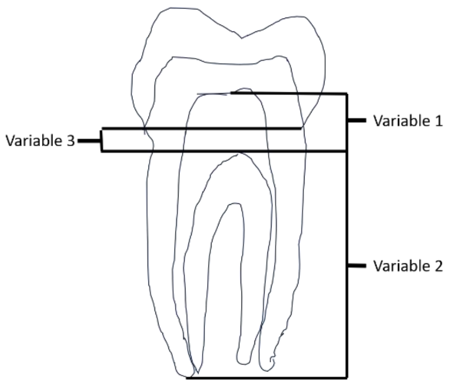

Figure 1. The taurodontism index of Shifman and Chanannel. Variable 1: the vertical height of the pulp chamber. Variable 2: the distance between the lowest point of the roof of the pulp chamber and the apex of the longest root. Variable 3: the distance between the baseline connecting the two cementoenamel junctions and the highest point in the floor of the pulp chamber.

However, pulp chamber elongation is probably a continuum, the point at which a tooth is termed taurodontic must rely on arbitrary criteria [67]. This reliance on arbitrary criteria foster disagreement among various studies of this dental trait [1, 5, 67].

Although the aetiopathogenesis of taurodontism is still unclear, most studies considered that taurodont is due to the failure [10, 11, 15, 18, 50, 68] or delay in invagination of diaphragm of Hertwig's epithelial sheath [9, 28] or if the Hertwig epithelial root sheath breaks at an inappropriate level [25] inducing an abnormal horizontal level of the future root furcation, and thereby enlarging the tooth body and pulp chamber and shortening the roots [3, 21, 26, 27, 44, 64, 67]. The dentin [10] and the cementum of taurodontic tooth is normal [10, 12]. Also, taurodontism arises when the formation of the epithelial bridges in the area of the future furcation is delayed [12]. The *CACNA1S* (*Calcium Channel voltage-dependent, L-type, Alpha-1S subunit*) variant seems to cause impaired dental epithelial folding; too much folding in the molars and less folding in the premolars; and delayed folding (invagination) of Hertwig epithelial root sheath, which resulted in single-rooted molars or taurodontism [69].

Other authors argue that taurodontism represents an unusual developmental pattern [13, 28], a delay in the calcification of pulp chamber [13, 28], an odontoblastic deficiency or the result of disrupted developmental homeostasis [24]. The other possible aetiologies are genetic, with the influence of the Wnt10A gene [70, 71] (loss of Wnt10A function [25], missense pathogenic variants in KIF4A [72] gene located on the X chromosome, and implicated in a pathogenic mechanism that also produces taurodontism, microdontia and dens invaginatus phenotypes [72], and MSX1 gene mutation [73].

Gene DLX3 that was identified in taurodontism associated with syndromes is expressed later during root morphogenesis [8, 41, 57, 74, 75]. DLX3 frame shift mutation (deletion [74]) was also identified in the hypoplastic–hypomaturation variety of amelogenesis imperfecta with taurodontism syndrome [12, 44, 74]. Loss of Eda pathway (EDA-A1 mutation) controlling the formation of furcation was responsible for the presence of taurodontism [76]. Finally, taurodontism aetiology may be related with developmental disturbances, and with syndromes (Table 1) [3, 21].

Taurodontism is found in healthy individuals [1, 3, 10, 18, 46, 59] as well as in specific syndromes (Table 1). The anomaly has been described together with congenitally missing teeth and hypodontia (preferential association between dental agenesis and taurodontism [8, 24, 65], maxillary lateral incisor and taurodontism [71, 77-81], oligodontia [65, 82-86], with talon cusp incisors [87, 88], with supernumerary premolars [89], in many syndromes, in sex chromosome anomalies with extra X chromosomes [1, 13, 15, 16, 25, 38, 50, 82, 85, 90], and in persons with cleft lip and palate [7, 24, 26, 47, 91, 92]. Sixty seven other syndromes were reported to present with taurodontism (Table 1).

Table 1. Syndromes related with taurodontism.

Syndrome name	**References in the literature**
Klinefelter's syndrome (XXY type, and the XXY/XXXY, XXXY, XXXXY, and XXXXY/XXXY variants [23]	1-4, 6, 7, 9, 13-15, 18, 20, 22, 25-29, 32, 38, 43, 44, 46, 47, 50, 57, 64, 65, 67, 81,82, 91, 93, 94
Down's syndrome (trisomy 21)	1-4, 6, 7, 9, 13, 15, 16, 18, 20, 22, 24, 26-28, 32, 38,43, 44, 46, 47, 50, 57, 64, 65, 81, 82, 91, 94-96
Tricho-dento-osseous syndrome (variants in a transcriptional regulator, Distal-less homeobox 3 gene, *DLX3* [75])	2-4, 6, 9, 12-16, 18, 25, 26, 29, 32, 38, 41, 44, 47, 57, 64, 67, 74, 81, 82, 91, 93, 94, 97
Mohr syndrome (Oro-facial digital type II syndrome)	2, 3, 6, 7, 9, 13, 15, 16, 24, 26, 28, 31, 38, 43, 47, 64, 67, 94
Echodactyly ectodermal dysplasia-cleft lip/palate (EEC)	3, 9, 13, 14, 16, 22, 25, 29, 31, 47, 64, 65, 81, 82, 85, 98
Amelogenesis imperfecta type IV (hypo-maturation-hypoplastic with taurodontism)	3, 10, 13, 29, 39, 50, 64, 65, 67, 74, 75, 81, 82, 91, 99, 100
Wolf Hirschhorn syndrome	6, 16, 20, 28, 44, 64, 94, 101
Chondroectodermal dysplasia (Ellis-van Creveld syndrome)	33, 44, 93, 94, 102, 103
X-chromosome aneuploid syndrome with ectodermal defects	2, 4, 10, 13, 15, 44, 67
Williams syndrome	16, 44, 64, 93, 94, 104
Oculo-cerebro-renal syndrome (Lowe syndrome)	6, 16, 28, 44, 64, 94
Smith-Magenis syndrome	16, 44, 47, 64, 93, 94
Apert syndrome	26, 44, 47, 64, 94
X-linked hypophosphatemic rickets	15, 18, 47, 81, 105
McCune-Albright syndrome	16, 44, 64, 93, 94
Van der Woude syndrome	7, 16, 24, 44, 93
Oculo-dento-digital dysplasia (Meyer-Schwickerath syndrome)	13, 14, 40, 64
Osteogenesis imperfect (Helical α2 glycine substitutions only caused taurodontism in lower second molars, while c-propeptide variants only caused taurodontism in upper second molars	106-108
Focal dermal hypoplasia (Goltz-Gorlin syndrome, X-linked dominant syndrome)	38, 64, 75
Microcephalic dwarfism-taurodontism root resorption (Sauk syndrome)	13, 64, 67
Seckel syndrome	44, 94, 109
Dyskeratosis congenital	64, 110, 111
Prader-Labhart-Willi syndrome	20, 44, 94
XXYY syndrome (double male syndrome)	20, 94
XXX chromosome syndrome	13, 15
XYY syndrome	13, 15
Hypohidrotic ectodermal dysplasia linked	13, 79

to the X-chromosome	
Hypo-hyperdontia	78, 112
Microdontia-taurodontia-dens invaginatus (Casamassimo syndrome)	64, 67
Ankyloblepharon-ectodermal defects-cleft lip/palate (AEC)	25, 98
Rapp Hodgkin syndrome	64, 98
Trichoonychodental syndrome	13, 44
Laurence-Moon-Bardet-Biedl syndrome (LM/BBS)	25, 113
Lenz microphthalmia syndrome	44, 94
Kabuki syndrome	44, 94
Osteoporosis	3, 9
Mucopolysacharidoses	114, 115
Hyperphosphatasia-oligophrenia-taurodontism	64
Syndrome X-fragile (Martin-Bell syndrome	90
Oculo-auriculo-vertebral syndrome (Goldenhar syndrome)	116
18p11.3 deletion	64
Nance–Horan syndrome (NHS) or X-linked cataract dental syndrome	48
Torg-Winchester syndrome	62
Pyle disease	62
Maroteaux-Lamy syndrome	2
Scanty hair, oligodontia, taurodontism	67
Pierre Robin syndrome	20
Clouston syndrome	117
Solitary median maxillary central incisor syndrome (SMMCI)	31
Bilateral familial taurodontism of deciduous molar teeth	28
Mucopolysaccharidosis Type VII (MPS7, also called β-glucuronidase deficiency or Sly syndrome	118
Dwarfism	65
Mulvihill–Smith syndrome	119
Non-syndromic Pierre Robin sequence	42
Cystinosis	120
Amelo-onchyo-hypohidrotic syndrome	13
Dubowitz syndrome	84
Periodontal Ehlers-Danlos syndrome	121
Dyke-Davidoff-Masson syndrome	43
Waardenburg syndrome type 1	122
Thalasseamia major	47
Progressive familial intrahepatic cholestasis	86
Osteopathia striata with cranial sclerosis	123

Molar incisor hypomineralisation	124
Families with WNT10A defects	20
SATB2-associated syndrome	125
Mutation in CACNA1S (*Calcium Channel voltage-dependent, L-type, Alpha-1S sub-unit*) associated with multiple supernumerary cusps and root ill development and taurodontism	69

Taurodontism arises also because of childhood cancer treatment [12, 126], especially after chemotherapy [127-129]. Moreover, taurondontism appears in consanguineous marriage [85, 130]. There exist also some pathological situations with enlarged pulp chamber mimicking taurodontism (Table 2).

Table 2. Differential diagnosis of enlarged pulp chamber like taurodonts radiographically.

Name of disease	**Description**
Pseudohypoparathyroidism	Teeth with enlarged root canals, with lack of an apical closure [14, 44]
Hypophosphatasia	Teeth hypocalcified and they harbour large pulp chamber, the teeth are lost because of cemental agenesis [2, 14, 64]
Dentinogenesis imperfecta	Large pulp chambers which result from the relative absence of dentin, normal furcation but smaller roots [14, 44]
Hypophosphataemia	The pulp horns rather than pulp chambers are elongated [14, 44, 82]
Regional odontodysplasia	Very thin enamel and dentin and a large pulp chamber, teeth usually fail to erupt [14, 26]
Dentinal dysplasia type 2	Large flame shaped pulp chambers, especially in premolars [14, 26], and even internal resorption of teeth [26]

Young permanent tooth may be mistaken for taurodontism but can be differentiated as it has wide apical foramina [44]. There is a large variability in the prevalence of taurodontism (from 0,1% to 48%) [21, 22, 35] among scientific publications [1, 67, 82] (Table 3).

Table 3. Variability in the prevalence of taurodontism among different countries and populations.

Country	Studies and prevalence
India	0.4% [53] 2.49% [132] 2.8% [16] 3.7% [131] 18% [45]
Iran	3.34% [56] 5.38% [55] 5.5% [17] 7.5% [58]
Saudi Arabia	0.1% [54] 1.3% [133] 1.4% [134] 11.3% [46]
China/Hong Kong	46.4% [46] 64% [37]
Senegal	48% [46, 55]
Israel	5.6% [46]
Italia	0.04% [135]
African American children	4.37% [46]
South Korea	3.9% [46]
Brazil	27.19% [68]

This may be explained by racial/ethnical variation (Table 3) and the difference between the inclusion criteria from a study to another (some study focusses on molars with or without exclusion of the third molars since other also includes premolars) [3, 5, 8, 16, 21, 25, 35, 29, 55, 67, 91, 131]. Furthermore, some studies based their diagnosis on dental radiographs [67], panoramic radiography (2D) [29] and other studies on CBCT (3D) [1, 25]. There are also differences in the literature about the tooth groups most affected by taurodontism. Some studies showed that mandibular second molar are most frequently affected [1, 67] while others report more cases in maxillary second molars [25]**.** The prevalence of taurodontism in deciduous teeth were reported to be 0.3% [24]. The prevalence of taurodontism in mandibular second molars in different populations, which would range from 0.13% to 1.2% [61]. Also, the prevalence of taurodontism increases as the number of X chromosomes increases [67, 91].

The gender-related taurodontism is also controversial. Some studies do not report a gender difference [9, 19, 29, 47] but other studies showed that this phenomenon occurs most frequently in men [16, 32, 47] or in women [131, 136].

In dentistry, taurodontic teeth with apical displacement of the pulpar chamber floor [91] present an endodontic challenge in each stage [1, 3, 4, 6, 7, 9, 13-19, 22, 24, 27-29, 32, 34-36, 44, 47, 50, 60, 64, 94, 137]: canal identification, cleaning, shaping and obturation because they present vertically elongated pulp chambers, apically displaced furcation areas, short roots, and lack of cervical constriction [2, 4, 64].

Increased bleeding during pulp chamber trepanation may be mistaken for perforation [9, 18, 28, 91]; Due to root shortening and the apical displacement of the pulpal chamber, floor perforations can occur [28, 91].

Furthermore, some authors report unusual variations in taurodont root canal morphology [3, 4, 44, 138], but such anatomical variation are also encountered in non-taurodontic teeth [91]. Endodontic success in taurodont is mainly accomplished using magnification [4, 6, 16, 35], passive ultrasonic irrigation [9, 35, 44] along with the modified instrumentation [4] and obturation techniques [4, 6, 9, 15, 35] but also by anticipating potential canal complexities for which CBCT is valuable. A combination of lateral condensation technique and warm vertical condensation technique may lead to satisfactory results [3, 4, 9, 10].

Because less surface area of the tooth is embedded in the alveolus, a taurodont tooth may not have as much stability as a cynodont when used as an abutment for either prosthetic or orthodontic purposes [1, 7, 22, 64].

When an orthodontic treatment is being planned, it must be noted that the anchorage values of taurodontic teeth may be reduced because of their reduced root surface area [14].

For the same reason taurodont tooth seems to be easier to extract [2, 3]. However, the tooth removal may be complicated by dilation of roots in the apical third [2, 29], if the roots are widely divergent [2, 3, 32], or because of the volume of the tooth [11]. Extraction of taurodontic third molars extending to the basilar may lead to mandibular fracture and for such cases coronectomy remains a valid option [11].

From the periodontal point of view, taurodont teeth may presents favourable prognosis [4] because the furcation involvement is considerably less common than in normal teeth [4, 7].

We present a case serie of 15 patients including different types of taurodontic teeth.

Materials and methods

We searched for articles with free full text about taurodontism. The search was performed by one observer on 23.08.2023 in PubMed database. The search equation was set as follows:

("taurodontic"[All Fields] OR "taurodontism"[Supplementary Concept] OR "taurodontism"[All Fields] OR "taurodont"[All Fields] OR "taurodonts"[All Fields]) AND (ffrft[Filter]).

Translations taurodontism: "taurodontic"[All Fields] OR "taurodontism"[Supplementary Concept] OR "taurodontism"[All Fields] OR "taurodont"[All Fields] OR "taurodonts"[All Fields].

The inclusion criteria were: open access articles, review articles, clinical studies, case series, and case reports. The exclusion criteria were: experimental study, animal study, forensic studies, articles without information on taurodontism, letters to editor, and articles with closed access.

We found 168 articles. 32 articles were excluded. Finally, 136 articles were retained for the review (Introduction, discussion) [1-62, 64, 65, 67-138].

Results

1. Unilateral mandibular first premolar (female patient, 69-years-old)

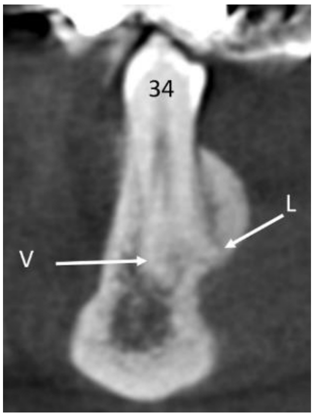

Figure 2. Planmeca Promax 3D Mid. 2D left sagittal view. Tooth n°34 with hypertaurodontism. Presence of two short and divergent roots V-vestibular and L-lingual. Lingual root inside the lingual cortical bone.

2. Unilateral mandibular second premolar (male patient, 30-years-old)

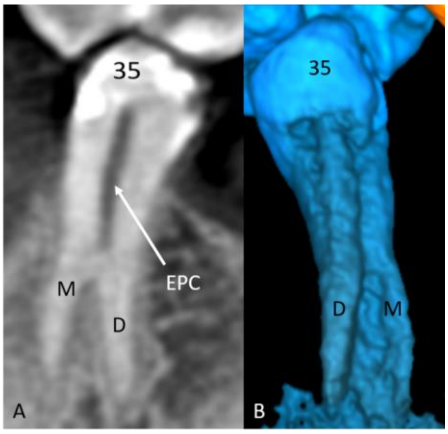

Figure 3. Planmeca Promax 3D Mid. A. 2D left sagittal view. Tooth n°35 with mesotaurodontism. EPC: elongated pulp chamber. Two short, thin, and divergent roots (M-mesial, and D-distal). B. 3D reconstruction of tooth n°35. Thin, and divergent roots (M-mesial, and D-distal).

3. Unilateral mandibular second premolar (female patient, 34-years-old)

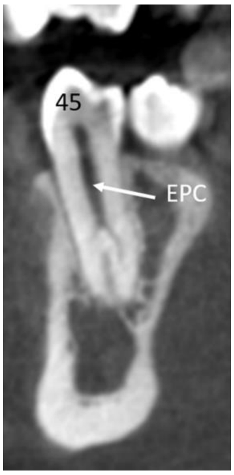

Figure 4. Planmeca Promax 3D Mid. A. 2D right sagittal view. Tooth n°45 with hypertaurodontism. EPC: elongated pulp chamber. Two short parallel roots.

4. Bilateral mandibular first and second premolar (female patient, 21-years-old)

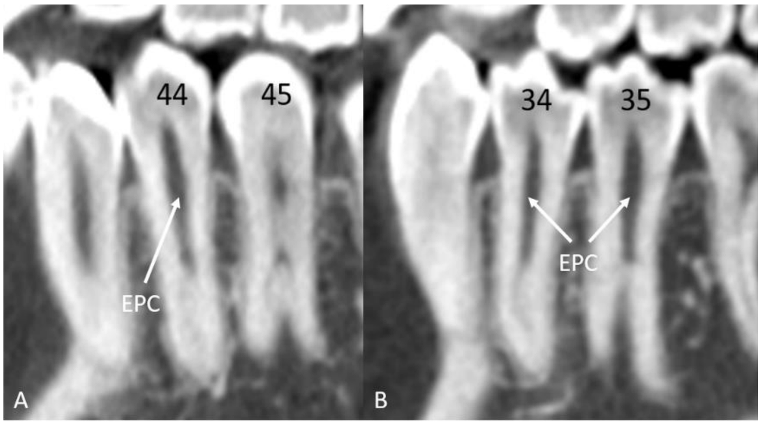

Figure 5. Planmeca Promax 3D Mid. A. 2D right sagittal view. Teeth n°44, 45 with hypertaurodontism. EPC: elongated pulp chamber. Tooth n°44 with one root and two canals. Tooth n°45 with two divergent roots. B. 2D left sagittal view. Teeth n°34, 35 with hypertaurodontism. Tooth n°34 with one root and one curved canal. Tooth n°35 with short, thin, and parallel roots.

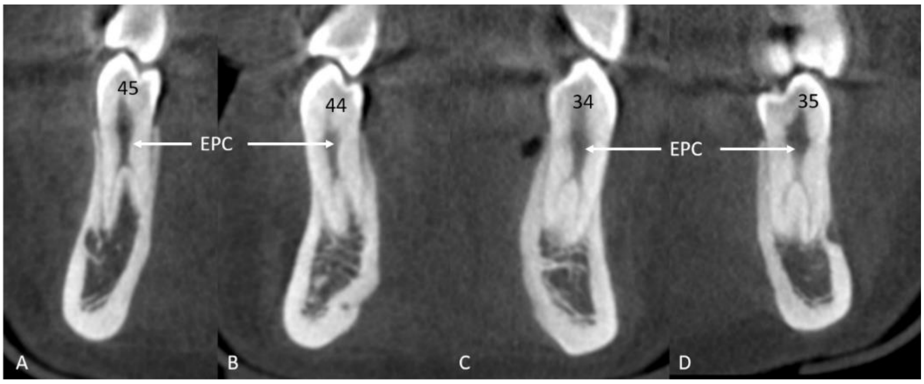

Figure 6. Planmeca Promax 3D Mid. A. 2D coronal view. EPC: elongated pulp chamber. A. Tooth n°45 with hypertaurodontism. Two short divergent roots (vestibular and lingual). B. Tooth n°44 with hypertaurodontism. Two short and parallel roots (vestibular and lingual). C. Tooth n°34 with hypertaurodontism. Two short and parallel roots (vestibular and lingual). D. Tooth n°35 with hypertaurodontism. Two short and parallel roots (vestibular and lingual).

5. Bilateral upper maxillary first premolars (female patient, 64-years-old)

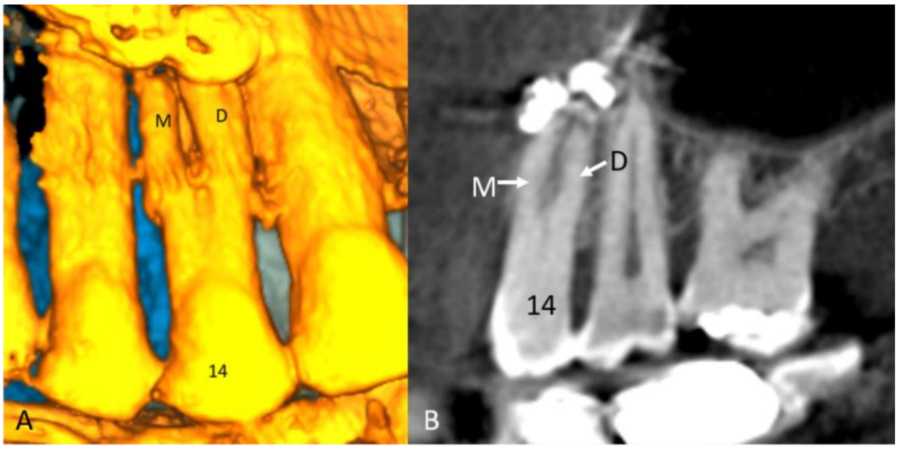

Figure 7. Planmeca Promax 3D Mid. A. 3D reconstruction of right upper maxillary dental arch. Tooth n°14 with hypertaurodontism. Two short and parallel roots (M-mesial, and D-distal). B. 2D right sagittal view. Tooth n°14 with hypertaurodontism. Two short and parallel roots (M-mesial, and D-distal).

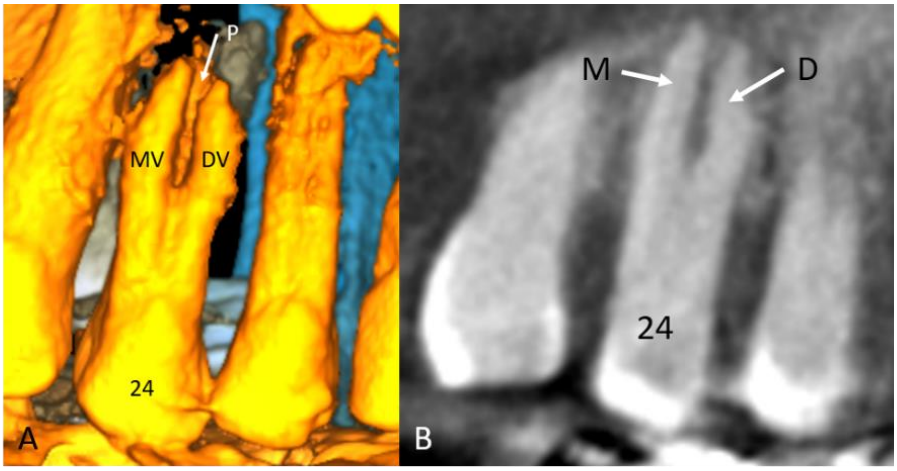

Figure 8. Planmeca Promax 3D Mid. A. 3D reconstruction of left upper maxillary dental arch. Tooth n°24 with hypertaurodontism, with three parallel roots: mesiovestibular (MV), distovestibular (DV) and palatine (P). B. 2D left sagittal view. Tooth n°24 with hypertaurodontism with two parallel roots M-mesial and D-distal.

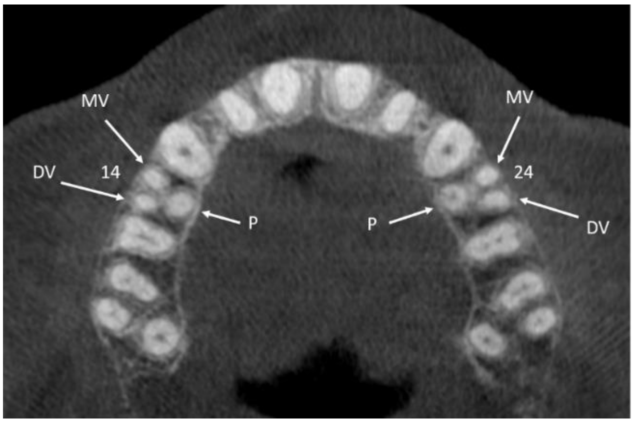

Figure 9. Planmeca Promax 3D Mid. 2D axial view. Tooth n°14 with hyper-taurodontism, and three roots (and canals): MV-mesiovestibular, DV-distovestibular, and P-palatine. Tooth n°24 with hypertaurodontism, and three roots (and canals): MV-mesiovestibular, DV-distovestibular, and P-palatine.

6. Bilateral mandibular second molars (male patient, 40-years-old), 1st case

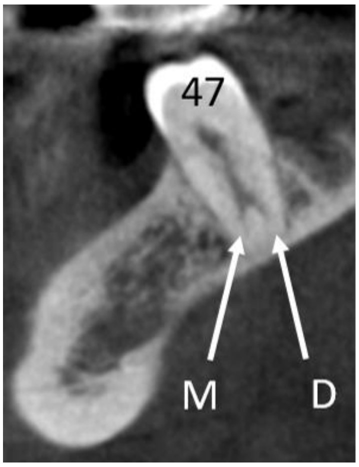

Figure 10. Planmeca Promax 3D Mid. 2D right sagittal view. Tooth n°47 with hypertaurodontism. Two short roots M-mesial and D-distal.

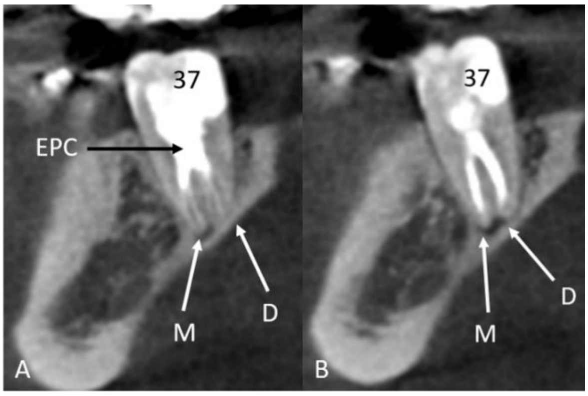

Figure 11. Planmeca Promax 3D Mid. 2D left sagittal view. Tooth n°37 with hypertaurodontism. A. Endodontic treatment of tooth n°37: EPC-elongated pulp chamber filled with obturation. Two short parallel roots M-mesial and D-distal. Rarefying osteitis at the apex of the mesial root of the tooth n°37. B. Endodontic treatment of tooth n°37: obturation of the mesial and distal canals. M-mesial and D-distal roots are convergent. Rarefying osteitis at the apex of the mesial root of the tooth n°37.

7. Bilateral mandibular second molars (male patient, 23-years-old), 2nd case

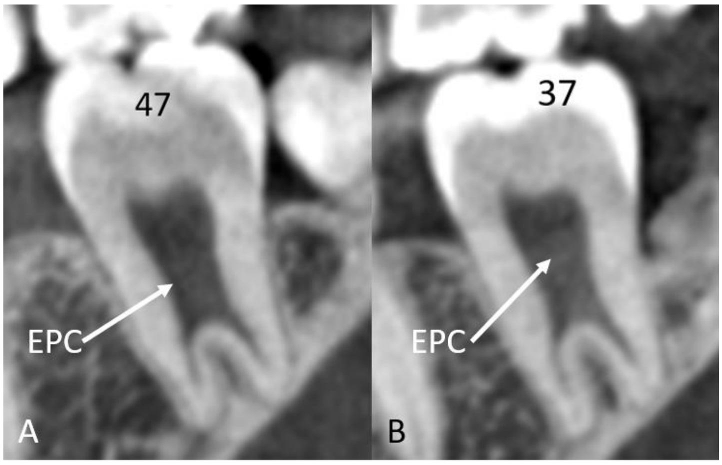

Figure 12. Planmeca Promax 3D Mid. 2D sagittal view. A. Tooth n°47 with hypertaurodontism. EPC-elongated pulp chamber. Two short and parallel roots. B. Tooth n°37 with hypertaurodontism. EPC-elongated pulp chamber. Two short and parallel roots.

8. Bilateral upper maxillary second premolar and left first molar (male patient, 55-years-old)

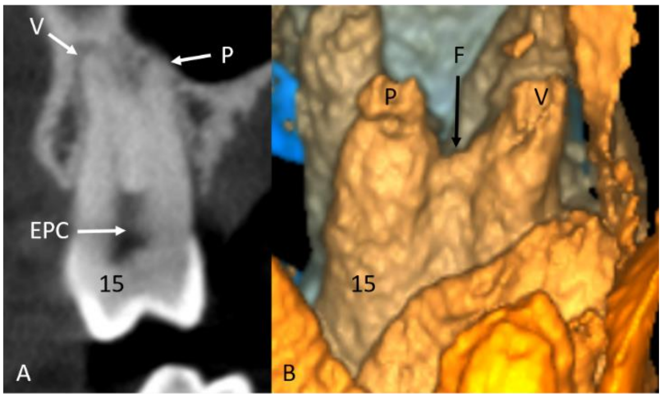

Figure 13. Planmeca Promax 3D Mid. A. 2D coronal view. Tooth n°15 with hypertaurodontism. EPC-elongated pulp chamber. Two short divergent roots V-vestibular, and P-palatine. B. 3D reconstruction of the right upper maxillary dental arch, upper view of furcation area of the tooth n°15 with hypertaurodontism. Two short roots V-vestibular, P-palatine, and F-furcation positioned apically.

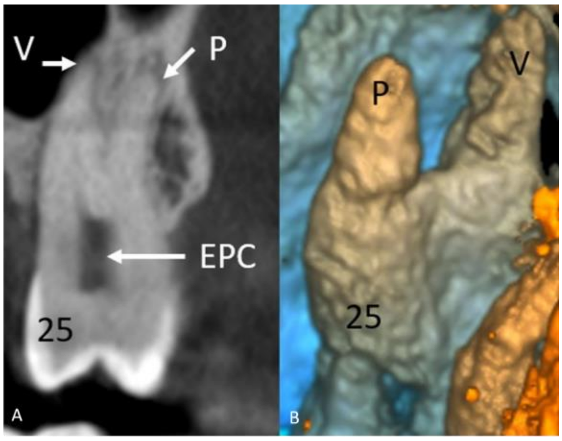

Figure 14. Planmeca Promax 3D Mid. A. 2D coronal view. Tooth n°25 with hypertaurodontism. EPC-elongated pulp chamber. Two short parallel roots: V-vestibular, and P-palatine. B. 3D reconstruction of the left upper maxillary dental arch, upper view of furcation area of the tooth n°25 with hypertaurodontism. Two short, and parallel roots V-vestibular, and P-palatine.

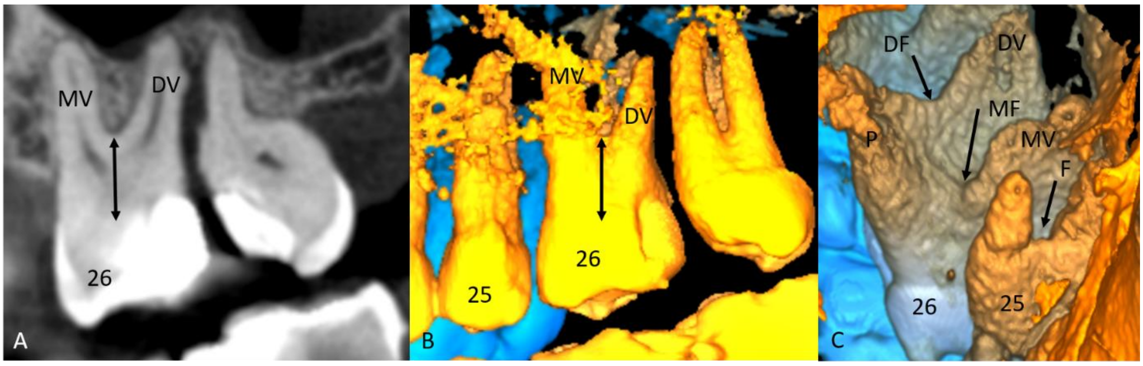

Figure 15. Planmeca Promax 3D Mid. A. 2D left sagittal view. Tooth n°26 with mesotaurodontism. Two divergent roots MV-mesiovestibular, and DV-distovestibular. Double arrow: increased distance between the crown and the level of the furcation. B. 3D reconstruction of the left upper maxillary dental arch, vestibular view. Tooth n°26 with mesotaurodontism. Two parallel roots MV-mesiovestibular, and DV-distovestibular. Double arrow: increased distance between the crown and the level of the furcation. C. 3D reconstruction of the left upper maxillary dental arch, upper view of furcation area. Tooth n°26 with mesotaurodontism with 3 roots: MV-mesiovestibular, DV-distovestibular, and P-palatine. MF-furcation between MV and P roots. DF-furcation between DV and P roots. Tooth n°25 with hypertaurodontism. F: furcation between vestibular and palatine roots.

9. Bilateral upper maxillary third molars (male patient, 79-yeaars-old)

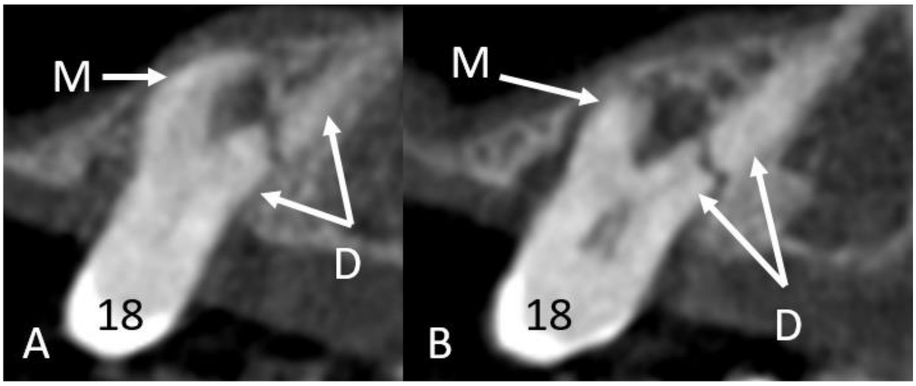

Figure 16. Planmeca Promax 3D Mid. A. 2D right sagittal view. Tooth n°18 with mesotaurodontism. M-mesial root curved distally. D-distal root divergent toward distal and with root fracture. B. Tooth n°18 with mesotaurodontism. Alveolar bone osteolysis around the M-mesial root and of the furcation area.

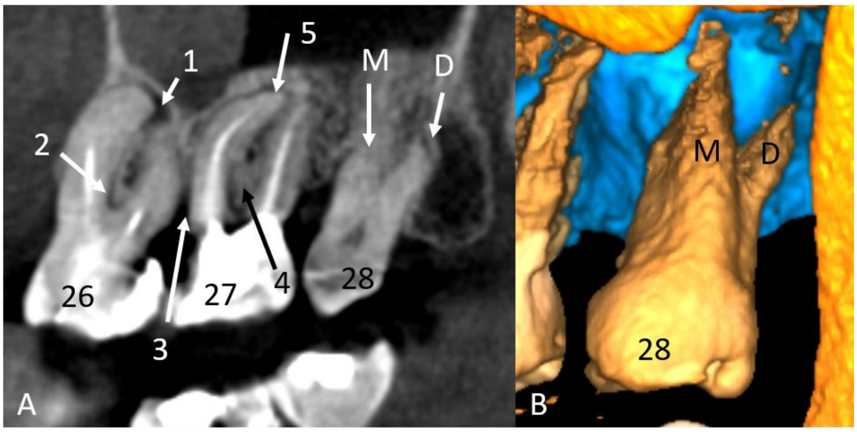

Figure 17. Planmeca Promax 3D Mid. A. 2D left sagittal view. Tooth n°28 with mesotaurodontism, with two divergent roots M-mesial and D-distal. 1-rarefying osteitis around the apex of the mesiovestibular root of the tooth n°26. 2-furcation lesion. 3-interdental alveolar bone lysis between teeth n°26 and 27. 4-external resorption of the mesiovestibular root of the tooth n°27 and replacement by the alveolar bone. 5-rarefying osteitis around the apex of the mesiovestibular root of the tooth n°27. B. 3D reconstruction of the tooth n°28. Tooth n°28 with mesotaurodontism, with two divergent roots M-mesial and D-distal.

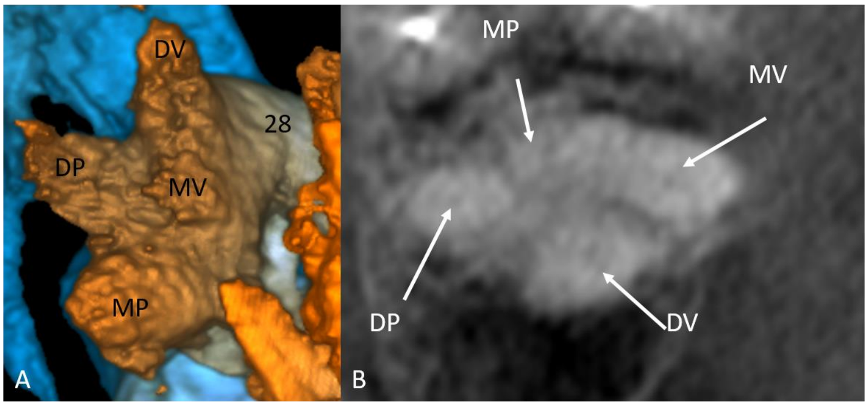

Figure 18. Planmeca Promax 3D Mid. A. 3D reconstruction of the roots of the tooth n°28. Tooth n°28 with mesotaurodontism, presents with 4 roots: MV-mesiovestibular, MP-mesiopalatine, DV-distovestibular, and DP-distopalatine. B. 2D axial view of the roots of the tooth n°28: MV-mesiovestibular, MP-mesiopalatine, DV-distovestibular, and DP-distopalatine.

10. Bilateral upper maxillary first and second molars (male patient, 14-years-old)

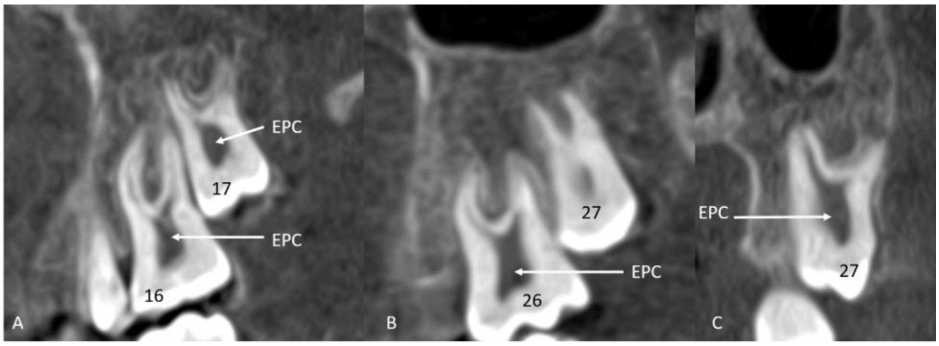

Figure 19. Planmeca Promax 3D Mid. A. 2D right sagittal view. Tooth n°16 with mesotaurodontism, with two vestibular convergent roots. EPC-elongated pulp chamber. Tooth n°17 with hypertaurodontism with EPC with two vestibular divergent roots. B. 2D right sagittal view. Tooth n°26 with hypertaurodontism with EPC with two vestibular convergent roots. Tooth n°27 with hypertaurodontism with two parallel vestibular roots. C. 2D coronal view. Tooth n°27 with hypertaurodontism, with EPC, and with vestibular and palatine divergent roots.

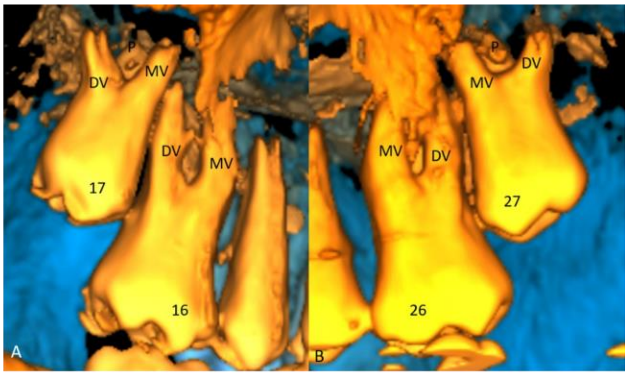

Figure 20. Planmeca Promax 3D Mid. A. 3D reconstruction of right upper maxillary dental arch, right lateral view. Tooth n°17 with hypertaurodontism, with divergent roots: MV-mesiovestibular, DV-distovestibular, and P-palatine. Toth n°16 with mesotaurodontism with parallel vestibular roots: MV-mesiovestibular and DV-distovestibular. B. 3D reconstruction of left upper maxillary dental arch, left lateral view. Tooth n°27 with hypertaurodontism, with divergent roots: MV-mesiovestibular, DV-distovestibular, and P-palatine. Toth n°26 with mesotaurodontism with convergent vestibular roots: MV-mesiovestibular and DV-distovestibular.

11. Bilateral upper maxillary first, second, and third molars (female patient, 16-years-old)

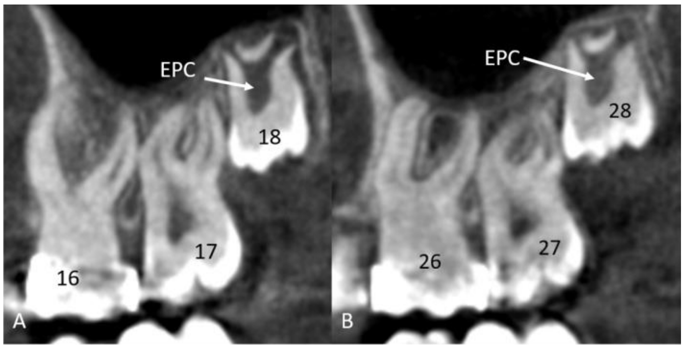

Figure 21. Planmeca Promax 3D Mid. A. 2D right sagittal view. Tooth n°16 with mesotaurodontism with vestibular convergent roots. Tooth n°17 with hypertaurodontism with vestibular convergent roots. Growing and impacted tooth n°18 with hypertaurodontism with EPC-elongated pulp chamber. B. 2D left sagittal view. Tooth n°26 with mesotaurodontism with vestibular convergent roots. Tooth n°27 with hypertaurodontism with vestibular convergent roots. Growing and impacted tooth n°28 with hypertaurodontism with EPC-elongated pulp chamber.

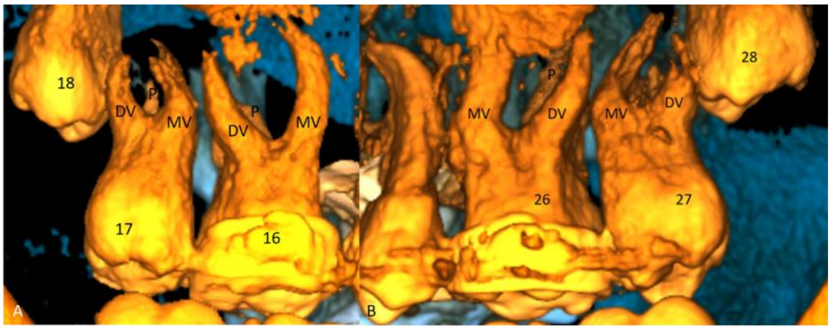

Figure 22. Planmeca Promax 3D Mid. A. 3D reconstruction of right upper maxillary dental arch, right lateral view. Impacted tooth n°18. Tooth n°17 with hypertaurodontism with convergent roots: MV-mesiovestibular, DV-distovestibular, and P-palatine. Tooth n°16 with mesotaurodontism with divergent roots: MV-mesiovestibular, DV-distovestibular, and P-palatine. B. 3D reconstruction of left upper maxillary dental arch, left lateral view. Impacted tooth n°28. Tooth n°27 with hypertaurodontism with convergent roots: MV-mesiovestibular, and DV-distovestibular. Tooth n°26 with mesotaurodontism with divergent roots: MV-mesiovestibular, DV-distovestibular, and P-palatine.

12. Bilateral upper maxillary (third molars, second, and first left upper molars), and mandibular molars (first right, and left mandibular molars, right third molar) (female patient, 39-years-old)

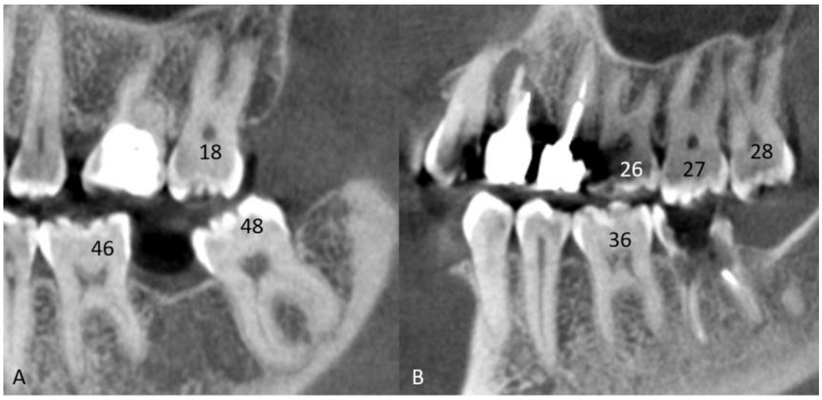

Figure 23. Planmeca Promax 3D Mid. A. 2D right sagittal view. Tooth n°18 with mesotaurodontism, and parallel roots. Tooth n°48 with mesotaurodontism with curved and convergent roots. Tooth n°46 with hypotaurodontism. B. 2D left sagittal view. Tooth n°28, 27, and 26 with mesotaurodontism, and parallel roots. Tooth n°36 with mesotaurodontism with parallel roots.

13. Bilateral upper maxillary molars (first, second, third right, and left upper molars), and mandibular molars (36-37, 46-47) (male patient, 35-years-old)

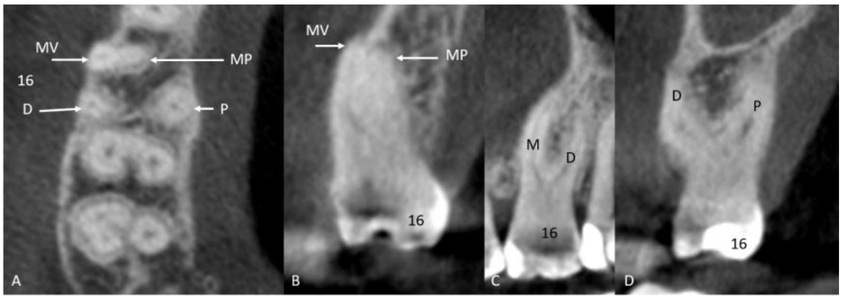

Figure 24. Planmeca Promax 3D Mid. A. 2D axial view of roots of the tooth n°16, with mesotaurodontism, with 3 roots Mesial, distal (D) and palatine (P). Mesial roots present with two canals: MV-mesiovestibular and MP-mesiopalatine. B. 2D coronal view of the mesial root of the tooth n°16; MV-mesiovestibular and MP-mesiopalatine canals. C. 2D right sagittal view. Tooth n°16 with mesotaurodontism with two vestibular parallel roots: M-mesial, and D-distal. D. 2D coronal view. Tooth n°16 with mesotaurodontism with two divergent roots: D-distal, and P-palatine.

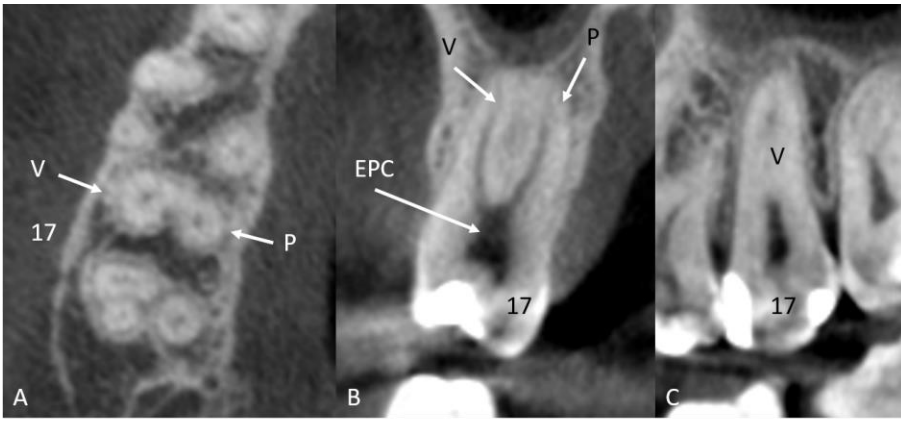

Figure 25. Planmeca Promax 3D Mid. A. 2D axial view of the tooth n°17 with mesotaurodontism. Tooth n°17 with two roots: V-vestibular and P-palatine. B. 2D coronal view. Tooth n°17 with mesotaurodontism, with two close and parallel roots V-vestibular and P-palatine, and with EPC-elongated pulp chamber. C. 2D right sagittal view. Tooth n°17 with vestibular root and EPC.

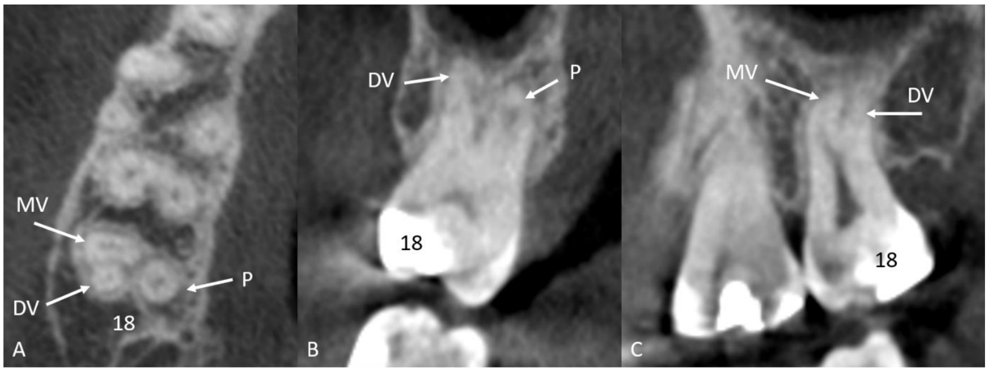

Figure 26. Planmeca Promax 3D Mid. A. 2D axial view of the tooth n°18. Tooth n°18 with hypertaurodontism, 3 roots: MV-mesiovestibular, DV-distovestibular, and P-palatine. B. 2D coronal view. Tooth n°18 with hyper-taurodontism and slightly divergent roots DV-distovestibular and P-palatine. C. 2D right sagittal view. Tooth n°18 with hypertaurodontism, with elongated pulp chamber, and with parallel roots MV-mesiovestibular, and DV-distovestibular.

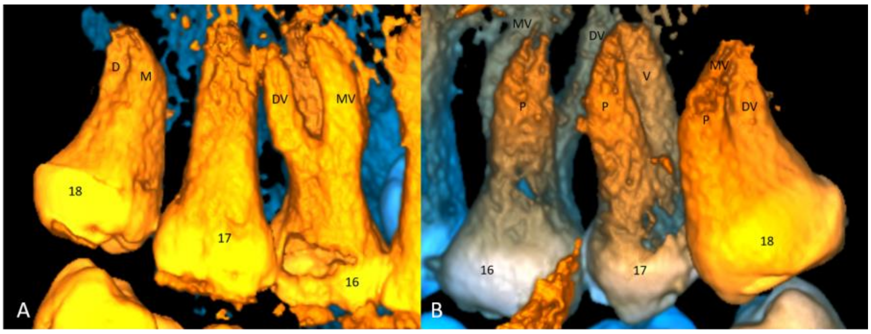

Figure 27. Planmeca Promax 3D Mid. A. 3D reconstruction of right upper maxillary dental arch, vestibular view. Tooth n°18 with hypertaurodontism and two visible and parallel roots D-distal and M-mesial. Tooth n°17 with mesotaurodontism. Tooth n°16 with mesotaurodontism and two parallel roots MV-mesiovestibular and DV-distovestibular. B. 3D reconstruction of right upper maxillary dental arch, palatine view. Tooth n°18 with hypertaurodontism, and three parallel roots: MV-mesiovestibular, DV-distovestibular, and P-palatine. Tooth n°17 with mesotaurodontism, and two parallel roots, V-vestibular, and P-palatine. Tooth n°16 with mesotaurodontism, and three parallel roots: MV-mesiovestibular, DV-distovestibular, and P-palatine.

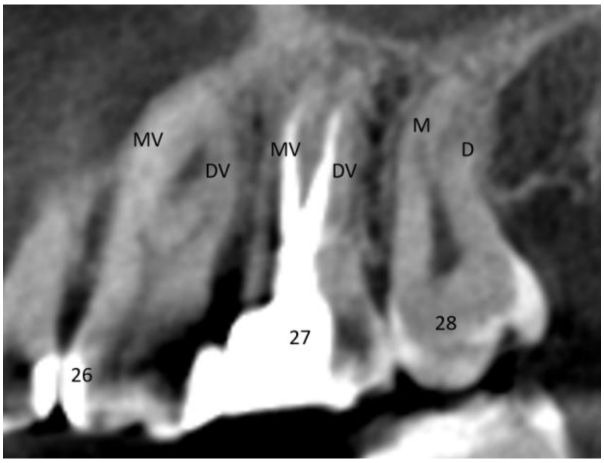

Figure 28. Planmeca Promax 3D Mid. 2D left sagittal view. Tooth n°26 with hypertaurodontism, and two convergent roots MV-mesiovestibular, and DV-distovestibular. Tooth n°27 with mesotaurodontism, with two parallel roots MV-mesiovestibular, and DV-distovestibular and endodontic treatment. Tooth n°28 with hypertaurodontism, with two parallel roots M-mesial, and D-distal.

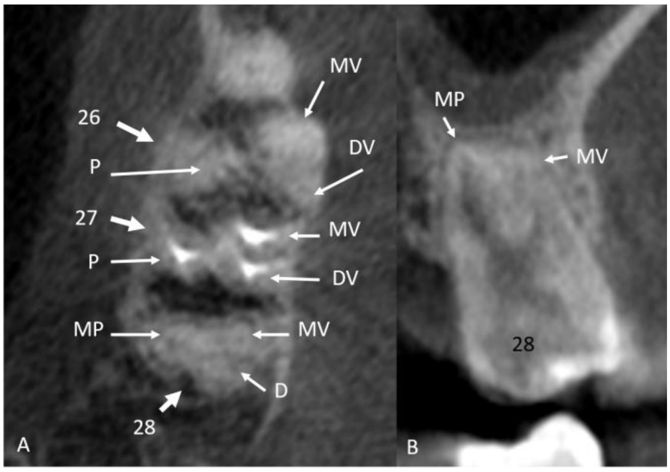

Figure 29. Planmeca Promax 3D Mid. 2D axial view. Tooth n°26 with three roots: MV-mesiovestibular, DV-distovestibular, and P-palatine. Tooth n°27 with three roots: MV-mesiovestibular, DV-distovestibular, and P-palatine. Tooth n°28 with three roots: MV-mesiovestibular, MP-mesiopalatine, and D-Distal. B. 2D coronal view through mesial roots. Tooth n°28 with hypertaurodontism, and almost the absence of furcation between MV-mesiovestibular and MP-mesiopalatine roots.

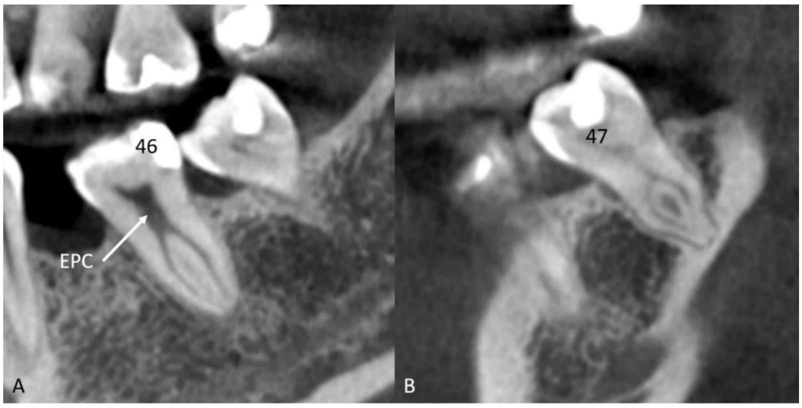

Figure 30. Planmeca Promax 3D Mid. A. 2D right sagittal view. Tooth n°46 with mesotaurodontism, EPC-elongated pulp chamber, and parallel roots. B. 2D right sagittal view. Tooth n°47 with hypertaurodontism, with convex and convergent roots.

Figure 31. Planmeca Promax 3D Mid. A. 2D left sagittal view. Tooth n°36 with mesotaurodontism, with parallel roots, with EPC-elongated pulp chamber, with endodontic treatment, and with rarefying osteitis and external root resorption of the distal root. B. 2D left sagittal view. Tooth n°37 with mesotaurodontism and two parallel roots.

14. Unilateral first mandibular premolar with cleft (female patient, 14-years-old)

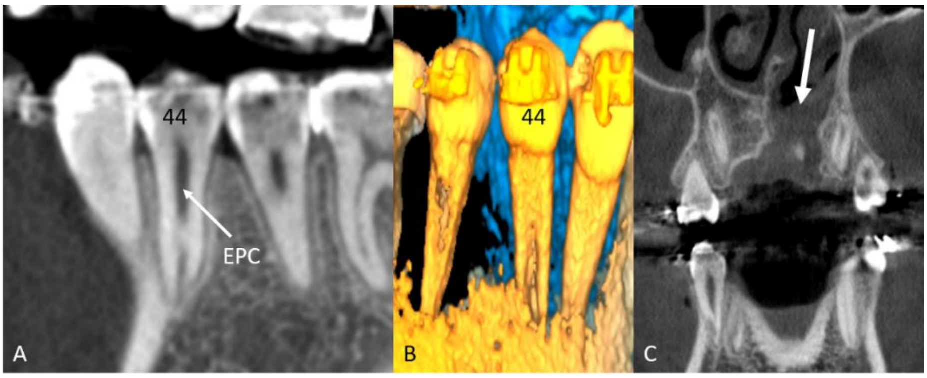

Figure 32. Planmeca Promax 3D Mid. A. 2D right sagittal view. Tooth n°44 with hypertaurodontism, EPC-elongated pulp chamber, and two parallel roots. B. 3D reconstruction of the tooth n°44 with hypertaurodontism, with very thin roots. C. Coronal view. Arrow: left cleft palate.

15. Bilateral molars of the mandible and the upper maxilla (female patient, 15-years-old, received chemotherapy at the age of 3-years-old to treat retinoblastoma)

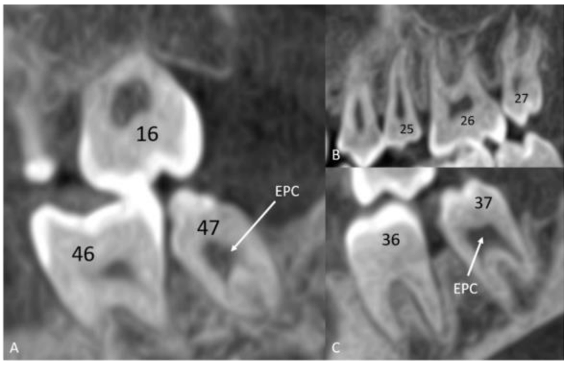

Figure 33. Planmeca Promax 3D Mid. A. 2D right upper maxillary and mandible sagittal view. Tooth n°16 without roots. Tooth n°46 with hypertaurodontism and very short triangular roots. Tooth n°47 with hypertaurodontism, conical crown, two convergent roots, and EPC-elongated pulp chamber. B. 2D left upper maxillary sagittal view. Tooth n°25 with microdontia. Tooth n°26 with mesotaurodontism. Tooth n°27 with hypertaurodontism, with two parallel roots. C. 2D left mandibular sagittal view. Tooth n°36 with hypotaurodontism. Tooth n°37 with mesotaurodontism and EPC-elongated pulp chamber. Diastema between teeth n°25-26, 46-47, 36-37.

16. Unilateral first maxillary molar (male patient, 19-years-old, Treacher-Collins syndrome)

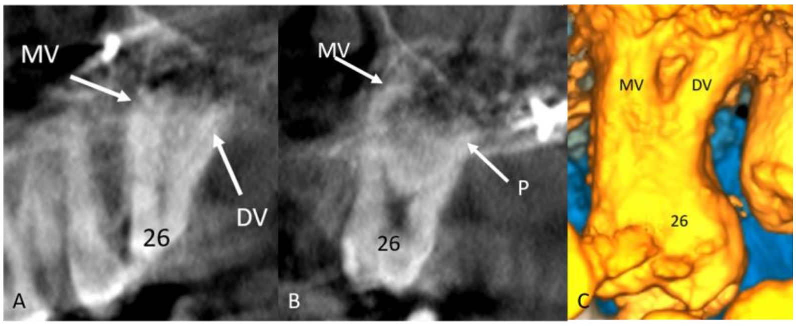

Figure 34. Planmeca Promax 3D Mid. A. 2D left sagittal view. Tooth n°26 with mesotaurodontism with two divergent roots MV-mesiovestibular and DV-distovestibular. B. 2D coronal view. Tooth n°26 with mesotaurodontism with divergent roots MV-mesiovestibular and P-palatine. C. 3D reconstruction of the tooth n°26. Tooth n°26 with mesotaurodontism, with divergent roots MV-mesiovestibular, and DV-distovestibular.

Discussion

We proposed a new clinical classification of taurodontic teeth based on hypo-, meso-, and hypertaurodontism, and on different types of deciduous and definitive teeth (Table 4). In the table 4 there exists 17/42 boxes with reference images accessible in free open access literature. Most of free reference images were related to: 1) hypertaurodontic upper maxillary first molar (16/26), 2) mandibular first molar (46/36), and 3) mandibular second molar (47/37). The free reference image of taurodontic tooth related with a syndrome was exceptionally present in the literature despite the extremely important number of syndromes associated with taurodontism (Table 1).

Table 4. Classification of taurodontic teeth [1, 15, 25, 27, 35, 36, 57, 59-62].

	Hypotaurodontism	Mesotaurodontism	Hypertaurodontism
Deciduous teeth			
Mandibular molars (84,85/74, 75)			
Upper maxillary molars (55, 54/64,65)			
Definitive teeth			
Upper maxillary canines (13/23)			

Mandibular canines (33/43)			
Upper maxillary first premolar (14/24)	[25]	[25]	[25] Fig. 8 Fig. 7
Upper maxillary second premolar (15/25)			Fig. 15 Fig. 14 Fig. 13
Mandibular first premolar (44/34)	[25]	[25]	[25, 36] Fig. 32 Fig. 7 Fig. 6 Fig. 5 Fig. 2
Mandibular second premolar (45/35)		Fig. 3	[35] Fig. 6 Fig. 5 Fig. 4
Upper maxillary first molar (16/26)		[25] Fig. 34 Fig. 27 Fig. 24 Fig. 23 Fig. 22 Fig. 21 Fig. 20 Fig. 19 Fig. 15	[1, 15, 27, 60] Fig. 28
Upper maxillary second molar (17/27)	[1, 25]	[1, 27] Fig. 28 Fig. 27 Fig. 25 Fig. 23	[25] Fig. 33 Fig. 22 Fig. 21 Fig. 20 Fig. 19
Upper maxillary third molar (18/28)		Fig. 23 Fig. 17 Fig. 16	Fig. 29 Fig. 28 Fig. 27 Fig. 26 Fig. 21
Mandibular first molar (46/36)	Fig. 33 Fig. 23	[27] Fig. 31 Fig. 30 Fig. 23	[15, 27, 62, 57]
Mandibular second molar (47/37)	[1, 25]	[1, 25, 62] Fig. 33, Fig. 31	[1, 25, 59, 61] Fig. 33 Fig. 30 Fig. 12 Fig. 11 Fig. 10
Mandibular third molar (48/38)		Fig. 23	
Associated with syndrome	[57] (TDO syndrome) Fig. 34 (Traecher-Collins)		
Related to chemo-therapy	Fig. 33		
Related with cleft palate	Fig. 32		

The 19/42 boxes are still empty (no free reference images available) and correspond to: 1) taurodontic deciduous teeth (6 boxes), 2) taurodontic canines (6 boxes), 3) upper maxillary second premolar (15/25) hypo- and mesotaurodontism, 4) mandibular second premolar (45/35) hypo-taurodontism, 5) upper maxillary first molar (16/26) hypotaurodontism, 6) upper maxillary third molar (18/28) hypotaurodontism, and 7) mandibular third molar (48/38) hypo- and hypertaurodontism.

We were first able to provide free reference images (6/42 boxes) for: 1) upper maxillary second premolar (15/25) hypertaurodontism, 2) mandibular second premolar (45/35) mesotaurodontism, 3) upper maxillary third molar (18/28) meso- and hypertaurodontism, 4) mandibular first molar (46/36) hypotaurodontism, 5) mandibular third molar (48/38) mesotaurodontism. We were also first to freely illustrate taurodontism related with chemotherapy, with cleft palate patients, and with Treacher-Collins syndrome.

A visual radiographic assessment is the most followed method for diagnosing taurodontism [14]. By using this method, severe forms of taurodontism may be recognized without much difficulty [14] (Table 4). However, the mildest form of taurodontism goes unnoticed [14].Hypotaurodontic tooth was the less represented type on free reference images available in the literature, and it represented in our study 9/14 empty boxes (Table 4). The use of CBCT did not reduce the difficulty of endodontic retreatment [27].

However, CBCT give information on number (Figures 9, 18, 24, 25, 29) and of shape of roots (Figure 33), and number of additional canals inside the roots (Figure 24). Moroever, taurodontic teeth were classically described as teeth with divergent roots [2, 3, 32] (Figures 2, 3, 6, 13, 15-17, 19, 20, 26, 34). However, we found parallel roots (Figures 4-8, 12, 14, 19, 20, 23-28, 30-33), and convergent roots in taurodontic teeth (Figures 11, 19-21, 23, 24, 28, 30, 33).

Taurodontism can express itself as a single entity or as a part of a syndrome [10] (Figure 34). Gardner and Girgis recommend that patients with meso- or hypertaurodontic teeth who do not have a syndrome known to be associated with taurodontic teeth should be consulted for chromosome analysis, as there is a high association of taurodontic teeth with X-chromosome aneuploidy syndromes [4, 94].

Finally, 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 [7, 10, 25, 48].

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- **Competing interests**: Prof R. Olszewski is Editor-in-Chief of Nemesis. Dr E. Fourneau declares no conflicts of interests.
- **Ethical approval**: We obtained the approval from our University and Hospital Ethical committee for this study (B403/2019/03DEC/542).
- **Informed consent**: Patients were exempted from the informed consent according to the ethical committee approval.

Authors contribution:

Author	Contributor role
Fourneau Eléonore	Data curation, Writing original draft preparation, Writing review and editing
Olszewski Raphael	Conceptualization, Investigation, Methodology, Data curation, Resources, Validation, Writing original draft preparation, Supervision, Writing review and editing

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