

Research Article

Cusp of Carabelli: Observations of an Odontogenic Trait

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Abstract

The “Cusp of Carabelli” (COC) is a non-functioning, accessory cusp positioned on the mesiopalatal surface of permanent maxillary molars, predominately first molars and primary second molars. This supplemental cusp has been studied for several hundred years regarding size ranges, ethnic and racial distributions and genetic and/or environmental etiologies.

The content of this report will explore the historical significance and specific terminologies applied to this unique cusp; as well as the morphogenesis, classification, incidence and frequency occurrences among human populations. Although the COC has been relegated to a sometimes obscure morphological curiosity or distantly studied trait characteristic of the human dentition/s, interestingly its existence could speculatively be associated with accessory internal tissue contents, carious lesion formation and appropriate restoration, or genetic trait expressions for population discriminations.

Keywords

Cusp of Carabelli; Maxillary molar; Supernumerary cusp

Introduction

Permanent maxillary first molars are “striking” teeth with large surface areas, including crown and root patterns that support the vertical dimension of occlusion as well as maintaining the continuity of the arches for correct alignment of the anterior and posterior teeth. Anatomically, the tooth includes: four or five cusps, three large cusps (Mesiobuccal [MB], Mesiopalatal [MP], Distobuccal [DB]), and a smaller, less developed Distopalatal (DP) cusp. The occlusal surface also contains four fossae, transverse and oblique ridges together with three specifically designed roots with excellent anchorage in the alveoli; spread in a manner to sustain heavy

occlusal forces, vertically & laterally. The maxillary first molar, thought of as a “cornerstone” tooth due to the eruption pattern (approximately 6 years of age) and location in the dental arch, is recognized as the largest tooth in the maxillary arch and the largest tooth, in volume, of the permanent dentition [1-3]. The primary functions include the crushing and milling of food during mastication through compressive and tensile forces applied [1,2].

Structurally, permanent maxillary first molars are quite imposing from a morphological perspective. One developmental trait exhibited clinically; that, depending upon the genetic predisposition, which enhances this quality, is commonly referred to as a supplemental or supernumerary “fifth-cusp”. This nonfunctional fifth cusp of the maxillary molar/s has been labeled as a “fifth lobe”, “supplemental” or “accessory cusp”, and

finally the most accepted term - “Cusp of Carabelli” (COC) and/or “Carabelli’s tubercle” [1,2]. The COC is located on the lingual (palatal) surface of the MP cusp, primarily of the permanent maxillary first molar, but also associated with the primary maxillary second molar (Figure 1 and 2) [1,2]. The cusp becomes progressively smaller from the first to third molars in the permanent dentition (Figure 3) and is found, uncommonly, on the permanent maxillary second molars while rarely occurring on the third molars [1,2].



Figure 1: Representative photograph of a permanent maxillary left first molar exhibiting a Cusp of Carabelli (COC) on the lingual surface of the Mesiopalatal (MP) cusp.



Figure 2a: Representative photograph of a primary maxillary left second molar exhibiting a COC on the palatal surface of the MP cusp.

The COC is also located on the MP surface of primary maxillary second molars. Primary maxillary second molars



Figure 2b: Same tooth as previous figure, with lingual viewpoint of primary maxillary second molar.



Figure 3: A progression (decrease in size) of COC from permanent maxillary first to third molar.

closely resemble the permanent maxillary first molars regarding external crown anatomy and to a limited degree, root positions. From an occlusal viewpoint, the surface includes transverse and oblique ridges, four fossa/pits, four major cusps, and usually, a COC. Interestingly, primary maxillary first molars display much the same crown anatomy as found on permanent maxillary premolars [1,2]. A study conducted by Kannapan and Swaminathan [4], comparing study models from permanent maxillary first molars and primary maxillary second molars, found that a COC trait or expression was exhibited on 67.5% of primary and 52.77% of permanent molars, with a predilection among females. Primary maxillary second molars revealing a COC can be susceptible to dental caries and the position of this cusp can impede the placement of bands for space maintenance [4].

Georg Carabelli (Carabelli György), Edlen von Lunkaszprie (Squire of Lunkaszprie) a Hungarian dentist, provided the first description and categorization of this “supernumerary

enamel tubercle” (tuberculum anomale) in 1842. Georg Carabelli, a professor of dental surgery in Vienna, Austria, was author of several publications describing various aspects of dentistry and dental anatomy. The noteworthy books, Systematic Handbook of Dentistry Volumes 1-2, published in 1831 and 1844 (posthumously) revealed descriptive illustrations of oral anatomy and were among the first authentic dental “text-books” originating from Europe [5,6]. Interestingly, the designation of “Cusp of Carabelli” or Carabelli’s Tubercle” is still one of a few anatomical terms describing odontogenic nomenclature that was originally attributed to the associative, assigning individual or “person of discovery” and is still utilized by the dental community in educational environments or as part of the clinical repertoire.

Early in the 20th century, reports were published attempting to connect the occurrence of a COC with patients afflicted by congenital syphilis, such as associated with a “mulberry molar” crown anomaly. Conflicting information resulted, without any scientific basis forthcoming correlating the two entities [7].

A classification scale for the degree and expression of this additional cusp “anomaly” was devised by Dahlberg in 1963 [8]. The scale ranges from “0” to “7”, with “0” indicating no manifestation or expression (ridge, pit, furrow) and “7” including a large enamel cusp or tubercle (height approaches that of a major cusp), projecting into the lingual groove area (Figure 4 and 5).



Figure 4: Representative photograph of a permanent maxillary left first molar displaying a “0” (score range of “0” to “7”) on the COC, Dahlberg scale.

Discussion

Human teeth are formed by a process called odontogenesis which includes several stages of development. The complex processes, histodifferentiation and morphodifferentiation, are categorized into growth (initiation, proliferation, histo/morpho-differentiation, apposition), calcification, eruption, and attrition periods. Embryonic cells develop during bud, cap, bell, and maturation stages - acquiring their functional assignments as well as providing for the basic size and shape of tooth components [8]. Enamel tissue is formed by



Figure 5: Representative photograph of a permanent maxillary right first molar displaying a “7” (score range of “0” to “7”) on the COC, Dahlberg scale.

ameloblasts which are derived from the enamel organ, comprised of outer and inner enamel epithelial cells. Dentin and pulp are formed from odontoblasts and mesenchymal cells which originate from the dental papilla. The dental follicle forms cementoblast (cementum), fibroblast (periodontal ligament), and osteoblast (alveolar bone) tissues [9].

A dental lobe or cone is a fundamental morphological division of a tooth crown and is a primary center of development, growth, and calcification. Therefore, cusps originate from lobes or cones [1,2]. The lobes grow & develop until fusion or coalescence occurs, with the junction that forms the union of these lobes referred to as developmental grooves. These two primary developmental landmarks - cusps and grooves contribute formally to molar crown organization. For the permanent maxillary first molar the sequence of cone or cusp initiation encompasses the development of structural components: MB (paracone), MP (protocone), DB (metacone), and DP (hypocone) representing the various corners or line angles of a permanent maxillary molar [10,11].

Tooth cones or lobes and finally the formation of cusps originate from the enamel organ which forms specialized areas or thickenings within the inner enamel epithelium referred to as enamel knots, with the number and size of cusps dependent upon the spacing between enamel knots. The enamel knot serves as a communication system for the tooth providing information concerning tooth development, also regulating the growth and arrangement of future tooth cusps [12].

Various studies [5,8,10,13-15] have described the COC being found in hominid (early human) species *Australopithecus* and Neanderthal man, with suggestions of an evolutionary development from a small groove to a well pronounced cuspal growth. The frequency of occurrence of the COC has been recognized to vary

depending upon racial populations [8,12,16-20]. The frequency is highest among modern Europeans (70%-90%) and lowest among Asian populations (35%-45%) [5,17]. Etiological factors for the COC includes both genetic and exogenous or phenotypic in origin, with most research agreeing that the phenotypical appearance of the cusp is genetically determined [5]. Another report [21] observed that the origination of the cusp, found at the enamel-dentin junction, is related to an enamel epithelium “folding” process. A study conducted by Kondo and Townsend [22] suggested that the cuspal trait is more pronounced in humans with prolonged or delayed development of the protocone or MP cusp of the permanent molars, indicating a longer period of time for the epithelial folding process to occur. Study results published in 2010 by Hunter et al., [23] dealing with the morphogenesis of the COC, substantiated previously reported findings [24] that a “patterning cascade model” could predict the size and presence of the COC expression based upon the formation of the paracone or MB cusp followed by the protocone or MP cusp development: 1) “teeth with smaller intercusp distances relative to crown size would be more likely to possess the COC and 2) teeth with the smallest intercusp distances relative to crown size would possess the largest COC”. This model of cusp development or morphogenesis indicates a gene expression alone and a relationship between heritable genes and developing enamel epithelium (phenotypical expression) [23,24]. Also, the cusp formation occurs bilaterally in the dentition and appears to be more prevalent in males although no significant sexual dimorphism has been determined [23].

Anthropologists and paleoanthropologists have utilized morphological trait characteristics in assessing modern human populations and evolutionary patterns of expression among hominid species [5,13-15]. The morphological development of human teeth can provide knowledge for population identification and/or racial determination [4]. Also, the occurrence of these anomalies can provide the dentist with information regarding the treatment and appropriate restoration of carious lesions based upon locality (Figure 6 and 7) [5]. Finally, from an evolutionary standpoint, the occurrence of the COC can provide a preview of the morphogenesis of a trait characteristic - into a neoteric cusp [23].



Figure 6: A complex amalgam restoration on the occlusal/proximal surfaces with an un-restored COC groove.



Figure 7: Example of a permanent maxillary left molar restored using a large amalgam restoration, with a large COC visible from an occlusal viewpoint. Should this tooth have been restored using complete crown coverage?

The potential formation of a new cusp, such as the COC, is comprehensible considering the evolutionary history of lower species and mammals and the increasingly complex series of developments regarding the form and function of various dentitions. Regarding evolutionary biology in comparative anatomy, four stages of odontogenic development have included: reptilian stage (Haplodont); early mammalian stage (Triconodont); triangular stage (Tritubercular); quadritubercular stage. From primitive single cone tooth crown formations (Haplodont) organized for the procurement of food only (reptiles) to the quadritubercular stage (primates, humans) including well developed teeth (crowns), originating from multiple growth centers, occluding in precise arrangements, not only for prehension and trituration of food-stuffs, but for allowance of the actions of protection and stimulation of the intraoral hard and soft tissues; the evolutionary process of simplification to complication or chaos should be noted [1].

Other odontogenic anomalies associated, particularly, with the posterior, maxillary region includes supernumerary teeth or microdontia - paramolars, “fourth molars” (Figure 8a and b) [9]. Paramolars are located in the maxillary arch palatal to the permanent molars, while the other forms of posterior supernumerary anomalies are found distal to the third molars (Figure 9). Other types of anomalies or developmental disturbances pertinent to the topic of this report include teeth affected by germination, fusion, and concrescence. Fusion and germination are closely related, including the joining of two tooth germs (separate roots), with the identifying feature consisting of the formation or appearance of one “tooth”, with or without separate pulp chambers (recognized radiographically). Concrescence is simply the union of two teeth (roots) at the cementum level. It must be recognized that supernumerary teeth are the formation and eruption of additional, separate teeth, while the other odontogenic anomalies arise during the developmental processes of odontogenesis (Figures 10a and b,11) [9].

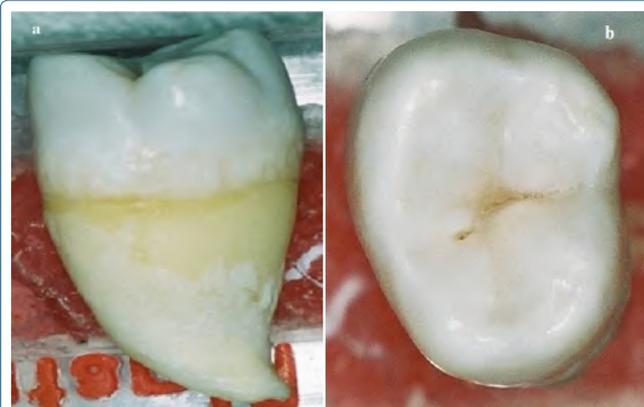


Figure 8a and b: Representative examples of a posterior supernumerary tooth or microdontia (these teeth could also be referred to as a maxillary “4th molar”).



Figure 9: Examples of paramolar teeth. A paramolar is a rudimentary form of microdontia located palatal to a maxillary molar (initiation stage of development).

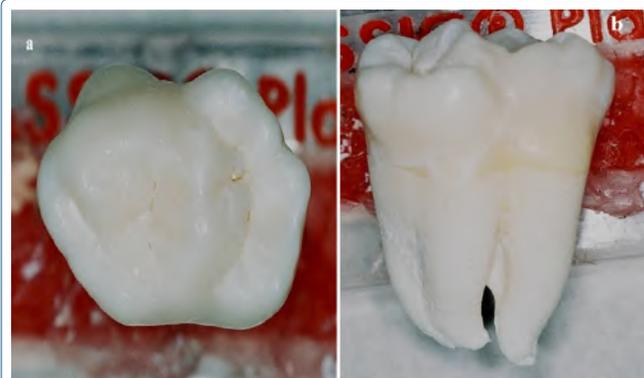


Figure 10a and b: Examples of odontogenic “fusion” or “germination”. Fusion: union of two posterior teeth with two pulp cavities (cap stage of development). Germination: union of two posterior teeth with two pulp cavities (cap stage of development).

Note: Difficult to ascertain between the two anomalies without radiographic verification.

The results of a study conducted by Moorman et al., [25] suggests that the “dentition develops, varies, and evolves as a single functional complex”, while another study [23] concluded that the COC trait can “occur as a byproduct of natural variation which impacts intercusp spacing and tooth size”. The origination of a new tooth crown or cusp also requires the introduction and development of supporting tissues necessary



Figure 11: Example of odontogenic “conrescence”. Union of two posterior teeth at the cementum level (apposition and maturation phases).

for the inclusive function of that structure. Using the COC as a model for conjecture, through the evolutionary process - from a supplemental enamel anomaly to a functioning cusp, originating from a primary growth center (cone), must this structure progressively develop internal and external characteristics necessary to sustain itself?

A recent study [26] reported endodontic management of a permanent maxillary molar which exhibited anatomic variations including a prominent paramolar palatal cusp and COC together with the observance of a supernumerary palatal root. A paramolar cusp is a supernumerary cusp located on the facial (buccal) or lingual (palatal) surfaces of premolars and molars and develops from secondary enamel knots [12]. With the addition of a paramolar cusp and COC, the study [26] also incurred a secondary root (canal), which was classified as a “unilateral formation-supradentalis”. From deductive reasoning, one might consider that with the occurrence of these types of crown/root formations reported in the aforementioned study, could be precursors to possible “internal development of separate pulpal contents” of the COC trait, or perhaps just aberrations.

Based upon the findings of the “supradentalis” report [26], the authors of the present study performed a simple *in vitro* procedure to visually validate the possible occurrence of internal tissues (blood vessels, nerve supply) associated with maxillary first molars containing prominent COCs (the authors could not locate a similar procedure performed following a review of the dental literature). The teeth were prepared in clear acrylic and sectioned from buccal to lingual in a sagittal plane through the center of each crown COC. Observation of the specimen sections clearly revealed internal structures (enamel, dentin, pulp cavity) as well as anatomical delineations between the MP and COC features; however, any association with pulpal contents was undistinguishable (Figure 12a and b). As previously cited [23], the simple occurrence of a substantial COC as a part of the maxillary molar (first molar) anatomy, could be indicative, evolutionary, of the formation of a “new” major cusp. However, speculatively this supposition might be, the eventual establishment of an additional cusp

could be significant regarding the inclusion of pulpal contents and therein, endodontic therapy.



Figure 12a: Sagittal section (20x) of a permanent maxillary left first molar.

Note: Separate, distinguishable MP cusp and COC internal morphology.



Figure 12b: Sagittal section (40x) of a permanent maxillary left first molar.

Note: A closer look at the MP cusp and COC internal morphology.

The inclusion of a fourth pulpal canal has only been routinely identified for successful treatment of a maxillary first molar requiring endodontic therapy. Upon navigation of an access opening into the pulp chamber for a maxillary first molar, based on current findings, the operator must assume that at least four canals are present (Mesio buccal 1 [MB1]; Mesio buccal 2 [MB2]; Distobuccal [DB]; and palatal). The palatal root can also include as many as three canals [3,27]. Often times, the MB2 canal, as well as other accessory canals, cannot be detected with the naked eye and therefore must be located and instrumented with a surgical microscope. However, with the advent of current specialized equipment, the mesio buccal canal “2” of the maxillary first molar - MB2 canal has been routinely recognized as an additional canal requiring treatment.

With this background information available, whether through the aid of modern armamentarium or the evolutionary process, the possibility that an additional pulpal canal in conjunction with the COC (trait) is speculative at present, but could perhaps be a reality in the future.

Conclusion

The findings of this literature review, exploratory report support the following conclusions:

- 1) The COC has been recognized as an accessory, minor cusp of maxillary molars, especially the maxillary first molar.
- 2) The COC was first identified and named by Georg Carabelli (Carabelli György), Edlen von Lunkaszprie (Squire of Lunkaszprie) a Hungarian dentist, in 1842.
- 3) The COC trait has been discovered in early hominin species and has a higher occurrence in the modern European races and lower occurrence in Asian races.
- 4) The COC trait can appear as a small groove on the mesio palatal surface or as a large, “full-formed” cuspal projection in the same locality.
- 5) A classification system exists identifying the various COC size limitations.
- 6) The literature has suggested that the occurrence of the COC can provide a preview of the morphogenesis of a trait characteristic - into a neoteric cusp.
- 7) Differences are incurred considering the COC and various odontogenic anomalies (supernumerary teeth, germination, fusion, concrescence).
- 8) A recent report identified the existence of a secondary root (canal), which was classified as a “unilateral formation-supradentalis” on/in the palatal root.
- 9) The preliminary findings from the present exploratory procedure included a visual representation of a sectioned maxillary first molar, including the COC, with a speculative hypothesis for a separate COC pulpal contents.

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