Tooth Cementum Annulation

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Tooth Cementum Annulation (or TCA) is a technique that relies on the analysis of the incremental growth of dental cementum for age and season at death estimation.

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1. Introduction

Tooth Cementum Annulation (or TCA) is the name attributed to a phenomenon that has been observed on the thinnest of the dental tissues: the cementum. Similarly to the other mineralised tissues, dentine and enamel, it shows a growth pattern strictly correlated to time. However, what makes the cementum (and specifically the acellular extrinsic fibre cementum—AEFC) more appealing is its property of growing throughout the individual's life without incurring in major remodelling. The term "annulation" (from the Latin word annuli for rings) refers to the tissue's characteristic of being laid down in "rings" made of alternating dark and light-coloured layers that correspond to winter and summer seasons. The combination of these factors (lifetime growth, extremely limited remodelling, and different seasonal layers) makes the cementum a sort of "time capsule" that scientists could use not only to determine an individual's chronological age, but also to infer some of their life history events.

Since the first publication about TCA (Laws [1]), enormous steps ahead have been taken towards the improvement and application of this technique. The focus and approach of these studies have been of the most diverse, e.g.,:

1. Age estimation
2. Season at death estimation
3. Nutritional/pathological factors
4. The biology of the tissue
5. Differences in methodologies and protocols
6. Improvement in histological practices
7. Adoption of formulae and measurements studies
8. Application of the technique on archaeological remains for historical studies, and on pathological and healthy samples either for biological studies or forensic investigations.

Interestingly, like Dawkins [2] would say, all these studies boomed as "not high-fidelity replicators" of the original Laws's theory [1], branching out in the most disparate directions, and are now being narrowed down (or, still following Dawkins, are now being "naturally selected") into the most efficient technique, so as to perfect the

understanding of the phenomenon and its potential as an anthropological tool. However, what is really needed, rather than other ways of counting the increments or measuring them for age assessments, is to go deep down to the causes behind the banding pattern and draw an evolutionary line that would answer questions such as “why did animals evolve in having this pattern?”, “what is its real function?”, and “how/why its deposition is regulated in a circannual rhythm?”. Filling these gaps with answers significantly and scientifically consistent would not only provide a better understanding of the biology of this elusive tissue, but would conclusively pose an end to all the controversies concerning the protocol to follow first and, eventually, to a less arguable acceptance of this technique in the forensic arena.

2. Brief History of TCA: First Studies

The first publication mentioning the TCA was in the 1950s, when Laws [1] claimed the development of “a new and accurate method of determining age, depending upon cyclical variation in the rate and manner of calcification of the teeth” from observations made on elephant seals. Since then, numerous other studies were carried out on animals (over 40 species of mammals according to Fancy [3] and over 50 according to Grue and Jensen [4]). Already in this first review, Fancy mentioned the variety of methodologies adopted and finally stressed the necessity of developing “standardized preparation and interpretation methods (…) for each species”. Only in the 1980s, Stott et al. [5] presented the first study of the TCA on humans. This laid the basis of the future Cementochronology, as it would later be called by Colard and colleagues in 2015 [6]. Later, Charles et al. [7] and Condon et al. [8] also applied the TCA on human samples, introducing for the first time some of the methodological issues that are still debated in the current literature (e.g., transverse/longitudinal sections; stained/unstained; demineralised or not; etc.). This represented a turning point in the history of the TCA studies. Afterwards, the research proceeded with animal studies on one side and humans on the other (sometimes both, such as in Klezeval [9]). These mostly pursued the improvement of the technique for age estimation but were also investigating secondary aspects according to the typology of the sample available (e.g., experiments on the development of the tissues, attempts on adopting the TCA as an identification tool, etc.). After the discovery of the phenomenon and the first successes of its applications, a few researchers started to address some of the main questions regarding its biological mechanisms. Significant to this was the research led by Lieberman (Lieberman and Meadow [10]; Lieberman [11][12]). In these papers, the author(s) outline for the first time the problem of the TCA: from its confusing terminology to the necessity of a better understanding of the biological differences between acellular and cellular cementum, to the necessity of a standardised protocol. In the following few years, another major contribution to the study of the TCA was given in 1996 by Klezeval [9], whose work was a massive compendium on the so-called “recording structures” in humans and several other animal species. In this book, the author gives details on the biology, functioning, and application of the “recording structures”—bones and teeth (cementum included). However, despite being a key point in the study of the TCA thanks to its systematic approach to the subject, this work is still significantly confusing in terms of terminology and methodology to adopt.

3. The Technique Based on the TCA Phenomenon

The general principle on which the technique for determining age-at-death from the TCA is based is that each pair of layers (one dark and one light) represents one chronological year and that the sum of all of them added to the specific eruption age of a tooth (or to its root completion) can give an estimate of the individual's chronological age at the moment of death. Determination of age-at-death from skeletal remains is one of the top aims of biological anthropology and, at the same time, one of its weakest points especially when it comes to adult individuals. All of the traditional anthropological methodologies for age estimation, in fact, produce estimates so wide as to become of little help the more mature the skeleton is (to cite only the main ones, see Brooks and Suchey [13]; Lovejoy et al. [14]; Buckberry and Chamberlain [15]; Meindl and Lovejoy [16]; Acsadi and Nemeskeri [17]; Iscan et al. [18][19]). Contrary to that, Cementochronology produced incredibly accurate estimates with a margin of error between 2.5 years [20] and 2.9 years [6]. Following experiments on animals also proved that the different bands' colour indicated a summer and winter season of about six months each. The analysis of the TCA for seasonal estimation is now called "Dental Cementum Increments Analysis" (or DCIA) by some, from Wedel and Wescott [21]. Likewise, the matter of age estimation, if not more importantly, the optimization of the DCIA in narrowing seasonal range estimations would finally open the possibility of assessing season-at-death and, thus, add an incredibly useful anthropological tool towards the determination of the post-mortem interval (PMI) in skeletal remains. Finally, cementochronology, TCA, and DCIA are really just different names to ultimately indicate the analysis of the dental cementum annulations.

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