Abstract

Aim: The aim of this study is to find out whether tooth length (crown length + root length) follows the rule of most divine and mysterious phi (φ) or the golden ratio. Methods: A total of 140 teeth were included in the study. The crown-root ratio was manually calculated using vernier caliper and its approximation to golden ratio or the divine number phi (φ) was examined. Results: The average root-crown ratio (R/C) for maxillary central incisor was 1.627 ± 0.04, and of its antagonist, mandibular central incisor was 1.628 ± 0.02. The tooth-root ratio (T/R) for the same was 1.609 ± 0.016 and 1.61 ± 0.008, respectively. Similar values were appreciated for lateral incisors where the R/C ratio in the maxillary and mandibular teeth was 1.632 ± 0.015 and 1.611 ± 0.012 and the T/R ratio was 1.606 ± 0.005 and 1.605 ± 0.005, respectively. Conclusion: On measuring the tooth length in linear fashion from the cusp tip to the root apex, we found that the tooth was divided into two parts at the cemento-enamel junction in the golden ratio. This information can be exploited in restorative and implant dentistry in future.

Keywords: Crown length, crown-root ratio, divine ratio, golden ratio, phi, root length

Introduction

The divine ratio or the golden ratio is omnipresent and has fascinated researchers since time immemorial. This divine ratio better known by the term “Phi” (φ) corresponds to the ratio of 1:1.618. Wasler defined the golden ratio as a line segment that is divided into the ratio of the larger segment being related to the smaller segment exactly as the whole segment is related to the larger segment.[1] The mathematical concepts of the golden ratio have been established throughout nature in architecture, medicine, music as well as in art, and numerous other disciplines. The ancient Greeks ascribed the discovery of this enthralling figure to Pythagoras, who defined human bodies symmetrically and in mathematical proportions. The golden ratio can be found not only in geometrical elements but also in living subjects including the human body.[2] Marcus Vitruvius Pollio portrayed that the height of a well-proportioned man is equal to the length of his outstretched arms.[3] The body and outstretched arms can be inscribed in a square, whereas the hands and feet are emblazoned in a circle. With this organization, the human body is divided into two parts at the naval. These parts are represented in the proportion of the golden rectangle or in the divine proportion. Classical statues of Doryphoros, the Spear-Bearer and Zeus from the 5th century, also have the proportions suggested above.[3]

Numerous points of view have transpired in regard to the proportions of the human body and its parts, rousing the interest of not only anatomists, scientists, and dentists but also of artists and aesthetes. Levin stated that if precisely seen in frontal view, the observable width of the maxillary central and lateral incisors, as the observable widths of the maxillary lateral incisors and canines, meet the golden ratio.[4]

While the proportion known as the golden mean has always existed in mathematics and physical universe and widely observed in nature, its origin and the first use by humankind remains veiled and cryptic. Perhaps, it has been discovered and rediscovered throughout the course of history and hence it is polyonymous. Nature is abundant with examples of golden proportion. It seems that the golden ratio or the divine proportion is a law of nature, imaginably the most widely observed and

How to cite this article: Anand R, Sarode SC, Sarode GS, Patil S. Human permanent teeth are divided into two parts at the cemento-enamel junction in the divine golden ratio. Indian J Dent Res 2017;28:609-12.
globally acknowledged. It is present in diverse cultures and is seen through civilizations since ancient times. The dimensions are not only aesthetically pleasing but also functionally efficient. The ratio has been observed in building of prodigious structures from the Egyptian pyramids, the great Parthenos in Athena to the human DNA. The number of studies in literature probing this astounding ratio is scarce and even meager subjected towards the oral cavity.

Teeth encompass about 60% of our mouth and are aesthetically and functionally the most important structure in the oral cavity. From providing appealing smiles to the function of mastication and load bearing, the relevance of teeth is multidisciplinary. With this thought in mind, we hypothesized that some aspect of tooth should follow the golden ratio. We decided to measure teeth in their linear dimension, from the incisal edge/cusp tip to the root apex with the dividing point at the cemento-enamel junction (CEJ) and discovering the approximation to the divine/golden ratio.

Materials and Methods

The study was carried out at Dr. D. Y. Patil Dental College and Hospital, Dr. D.Y. Patil Vidyapeeth, Pune, Maharashtra, India. The study was approved by the Institutes Review Board and Ethics Committee. A total of 140 extracted permanent teeth were collected from the Department of Oral and Maxillofacial Surgery at Dr. D. Y. Patil Dental College and Hospital, Pune. These were sorted into 14 groups comprising ten teeth of each class and seventy from each arch. All the teeth were immersed in sodium hypochlorite for disinfection and removal of debris.

Their crown and root lengths were measured and two ratios were calculated; the whole tooth length to the root length segment (tooth-root ratio [T/R]) and the root length to the crown length segment (root-crown ratio [R/C]). These were then correlated to find the approximation to the divine ratio.

Calculating the golden ratio

The divine ratio is the ratio of the larger segment, AB, of line AC to the smaller segment BC of the line AC.

Derivation

Let us assume that the total length of line AC is x + 1 units and the larger segment AB has a length of x. This would mean that the shorter segment BC would have a length of 1 unit. Now, we can set up a proportion of AC/AB = AB/BC.

By cross multiplying, it yields $x^2 - x - 1 = 0$. Using the quadratic formula, two solutions become apparent $(1+\sqrt{5})/2$ and $(1-\sqrt{5})/2$, and we only use the positive solution because we are expressing in terms of length. The positive solution is $(1+\sqrt{5})/2$. Phi is the only number that has the unique property that $\phi \cdot \phi' = -1$ where $\phi'$ is the negative solution to the quadratic $(1-\sqrt{5})/2$.

In the same manner, golden ratio for teeth was calculated as:

$$\frac{\text{Root length} + \text{Crown length}}{\text{Root length}} = \frac{\text{Root length}}{\text{Crown length}} \equiv \phi \ (1.618)$$

Sample

All 140 teeth were grouped according to their type into maxillary and mandibular central incisor, lateral incisor, canine, first premolar, second premolar, first molar, and second molar. Teeth with developmental anomalies, restorations, root resorption, vertical or horizontal fractures, attrition, abrasion, erosion, or any other regressive alteration were excluded from the study.

Measurement of crown and root length

Digital Vernier Caliper with a least count of 0.01 mm were used to determine the crown and root lengths. Crown length was measured on the facial aspect of the teeth from the deepest point in the CEJ to the incisal edges and cuspal tips of incisors and canines, respectively [Figure 1]. For measuring the crown length of molars, an imaginary line joining the cuspal tips on the facial aspect was drawn and the perpendicular distance between the deepest point on the CEJ and the imaginary line reflected the crown length of molars.

Root length was calculated in a similar manner as crown length from the deepest point in the CEJ to the root apex. In case of multirooted teeth, average of the mesial and distal root length was taken and documented.

Statistical analysis

All statistical analyses were carried out using Software (IBM SPSS statistics Inc.) version 20 (SPSS, Chicago, IL, USA). Mean and standard deviation of golden ratio was calculated for each group. Comparison of golden ratio in different groups was calculated using ANOVA test.

Results

The average R/C ratio for maxillary central incisor was $1.627 \pm 0.04$, and of its antagonist, mandibular central incisor was $1.628 \pm 0.02$. The T/R for the same was $1.609 \pm 0.016$ and $1.61 \pm 0.008$, respectively. Similar values were appreciated for lateral incisors where the R/C ratio in the maxillary and mandibular teeth was $1.632 \pm 0.015$ and $1.641 \pm 0.012$ and the T/R ratio was $1.606 \pm 0.005$ and $1.605 \pm 0.005$, respectively. R/C for maxillary canine was $1.636 \pm 0.015$ and the T/R was noted...
as 1.605 ± 0.007 which was comparable to its antagonist, mandibular canine where the R/C was 1.633 ± 0.014 and the T/R was calculated as 1.606 ± 0.005.

Similar results were observed among the other class of teeth, and no significant differences were found in the R/C ratio and T/R ratio among different groups of teeth. Descriptive statistics are presented in Table 1.

**Discussion**

The Parthenon at Athens is considered an impeccable man-made structure ever constructed and one that has survived centuries of neglect and insults. The reason for its continued existence is the fact that this structure inculcates the principle of divine proportion. The width of the building and its height are in golden sections.[6] The golden ratio can also be found in human DNA structure and has been found to be the only mathematical configuration that can duplicate itself ad infinitum without variance. A single DNA molecule measures 34 angstroms long by 21 angstroms wide for a full cycle of its double helix spiral.[7] Both 34 and 21 are Fibonacci numbers which converge to the golden ratio.

It has been suggested that this represents a geometrically encoded instructional pattern in the brain that guides humans to recognize beauty. The golden ratio is not only aesthetically pleasing but also structurally efficient. It is evident in many great structures from the building of Egyptian pyramids, Parthenon in the Athens to the human DNA. The Great Pyramid of Giza, Egypt was also built in harmony with the divine proportion; its vertical height and the width of any of its sides are in golden proportion. Hoggatt has cited further examples in which the golden section has been used.[8] These examples confirm Vitruvius’ statement that perfect buildings and proportionate human bodies have something in common.

Teeth have a multifunctional role in the oral cavity. Apart from keeping the oral tissues in harmony and providing appealing and aesthetic smiles and aiding in phonetics, their main task is mastication. According to a 1994 study by Zhao and Ye, human males can generate approximately 120 kg of biting force.[9] The size and shape of the teeth are predetermined and are vital structures in the oral cavity with respect to the amount of load they bear and the constant chemical and mechanical insults they suffer throughout the day. Hence, it was quite credible that some aspect of the tooth might follow the tenet of the golden section. In the present study, we studied crown length and root length of all the teeth for analysis of golden ratio. Surprisingly, these ratios were in close approximation to the golden/divine ratio corresponding to the value of 1.618.

Literature has a surplus mention of studies that have calculated the crown and root lengths of teeth by taking the mean and standard deviation[10,11] but none of these studies have analyzed and compared the ratio among root length and crown length on a single tooth. Since, mean values of root length and crown length are given separately, it was not possible to calculate golden ratio on previously published data and hence comparison with the previous literature was not possible.

Countless illustrations of the proportions of the golden section are found in the works of humans. The golden section follows on the basis of symmetry everywhere, and the forms which are based on the golden proportion are widely distributed.

The human face also depicts the golden ratio; the human head forms a rectangle with the eyes at the midpoint. The mouth and nose can each be placed at golden sections of the distance between the eyes and the bottom of the chin.[12] Dr. Stephen Marquardt created a

### Table 1: Comparison of mean crown-root ratio and mean tooth-root ratio among different sets of teeth

| Tooth type          | n  | R/C      | T/R      | R/C      | T/R      | F     | P     |
|---------------------|----|----------|----------|----------|----------|-------|-------|
| Maxillary CI        | 10 | 1.627±0.043 | 1.609±0.016 | 1.636±0.015 | 1.605±0.007 | 1.641±0.020 | 1.604±0.008 | 1.638±0.011 | 1.603±0.006 | 1.639±0.029 | 1.603±0.010 | 1.628±0.022 | 1.61±0.008 | 1.641±0.012 | 1.605±0.005 | 1.633±0.014 | 1.606±0.005 | 1.623±0.027 | 1.607±0.011 | 1.633±0.014 | 1.606±0.005 | 1.651±0.021 | 1.60±0.008 | 1.626±0.016 | 1.608±0.006 |
|                     |    |          |          |          |          |       |       |

*Insignificant result. CI=Central incisor, LI=Lateral incisor, C=Canine, PM=Premolar, M=Molar, R/C=Root-crown ratio, T/R=Tooth-root ratio, SD=Standard deviation.*
golden decagon mask, which is a two-dimensional visual perception of the face that has triangles with sides with ratios of 1:1.618.[13] This construct has been widely used since by plastic surgeons for aesthetic purposes worldwide. With the foregoing findings, it was natural to seek divine proportions in the dentition. The maxillary central incisors form a golden rectangle with phi ratio in height to width. The ratio of width of central incisor to the lateral incisor from the center is also phi.[14] On measuring the tooth length in linear fashion from the cuspal tip to the root apex, we found that the tooth was divided into two parts at the CEJ in the golden ratio. The ratio of R/C was similar to the ratio of T/R which was approximating the ratio of phi.

Considering a range of 0.61–0.63 for the golden ratio, Preston found it in only 17% of his sample between the widths of the maxillary central and lateral incisors.[15] Moreover, he did not observe this ratio between the widths of the maxillary central incisors and canines. In contrast, Snow emphasized that this ratio can be useful in the diagnosis of symmetry and proportion and in the creation of an aesthetically pleasing smile.[16] Rufenacht, Shillingburg et al., and Goldstein have recommended the golden ratio for the restoration of anterior teeth.[17‑20] Clinicians should incorporate the golden proportion while restoring the anterior teeth as it can be a powerful tool in determining good aesthetics. Moreover, the implication of the divine ratio should be subjugated in other disciplines of dentistry including orthodontics, prosthodontics, and implantology. The ratio is not only visually appealing but also functionally relevant. Integrating the golden ratio in dental implants, where the implant/crown length ratio is in harmony with phi would result in better adaptation and functionality of the implant. The ubiquitous divine ratio would also be useful in forensic dentistry as it is depicted in microscopic as well as macroscopic structures of the human body including the dimensions of the teeth and the face. Although, future studies in this section are needed for a better grasp of the implications.

Many conflicting theories exist about the origins of phi; however, we cannot deny the principles that accompany it. Whether it is the mathematical relationships that seem to form around the number or the sheer aesthetics of the proportion, we should be aware that φ is all around us and justly termed the divine ratio.

Conclusion
Within the limitations of the present study, it can be concluded that the golden ratio exists between the crown and root lengths of the maxillary and mandibular teeth. Future studies should focus on finding golden ratio in other macroscopic, microscopic, and submicroscopic aspects of teeth. This golden proportion principle can also be incorporated in the placement of dental implants wherein implant lengths should correspond to the ratio of phi. Future studies should focus on establishing the efficacy of functional relevance of the golden proportion in the prosthetic aspects.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

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