Correlation Between Body Measurements of Different Genders and Races

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1 Introduction

Phidias, a Greek sculptor and mathematician, first discovered ϕ, commonly known today as the Golden Ratio. Phidias studied the phenomenon of ϕ in various Greek sculptures, but Leonardo Da Vinci coined the term "Golden Ratio" by using it in some of his most famous works: "The Last Supper" and "Mona Lisa." In the portrait of Mona Lisa, the wife of an affluent Florence businessman, Da Vinci included numerous examples of the Golden Ratio, as he believed that the Golden Ratio represented an aesthetic bond between humanity and nature.

Human heads vary slightly in size and in different dimensions [5]. In this experiment, the only head dimensions that were considered were head width and head height and dimensions within the facial features. The "Golden Ratio," 1.618, is often considered the most visually appealing ratio in face proportions and other subjects, such as plants and trees. The fig tree is a good example of this ratio. However, there is not sufficient data supporting that the exact "Golden Ratio" is actually common within the human face [10]. Head size does not increase dramatically in small periods of time except in early life and when a head injury occurs [5]. Head height reaches its adult size in both girls and boys at the age of 13. However, head width continues to grow in most people until the age of 18 [2].

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Height can often accurately be estimated using arm span [1]. Correlation between arm span and height are often stronger among younger subjects; the two measurements are almost interchangeable. As people age, correlation often decreases. This is due to decreasing height in older subjects without significant decrease in arm span [7]. Leg length has also been known to correlate with height measurements, but arm span continues to provide the most reliable estimate [8]. There is strong existing data that humans are taller in the morning and shorter in the evening. This is because pressure on the spine during the day causes loss of fluid content in the intervertebral discs [3]. This was taken into account when measuring height in the experiment as students were asked to participate in the study in the morning and early afternoon.

All of the data gathered in this study was from a summer camp in 2012, Summer Ventures in Science and Mathematics at Appalachian State University. The ratios between arm span and height, and between head width and head height were analyzed to determine possible correlations. Head width is defined as the distance between the widest points on the left and right sides of the face. Head height was defined as the distance between the eye level and the chin. Formal statistical analyses such as t-tests and linear regression were then run on the data for testing the significance of any differences and correlations found. The concept of the Golden Ratio in humans was explored in both genders and all four races.

The outline of the paper is as follows. In Sect. 2, the Golden Ratio is described. Section 3 describes the sample. In Sect. 4, various body characteristics are introduced and in Sect. 5, descriptions of the distribution of these characteristics across races are examined. Statistical analyses and conclusions are discussed in section "Conclusion".

2   Golden Ratio

The distance from the bottom of Mona Lisa's right fingers to the top of her forehead is 1.618 times the distance from the bottom of her right fingers to the base of her neck. The right side of her face is then in golden proportion to the smaller of the original golden rectangle, as shown in Fig. 1.

Other ratios that are considered part of the Golden Ratio are: the distance starting from the base of the neck to the center of the pupil, and the base of the neck to the top of the forehead; the distance from the right side of the face to the right side of top of the nose, and the width of the face at that point; the distance from the bottom of the chin to the bottom of the lips, and the bottom of the chin to the bottom of the nose.

Although the Golden Ratio and Phenomenon of ϕ were invented in the eighteenth century, some of its principles are commonly used today, especially in architecture. The greatest example of Phi is the Parthenon as it uses the Golden Ratio measurements to obtain beauty and equilibrium to its design. Moreover, Notre Dame in Paris contains various Golden Ratio measurements despite its asymmetrical design.

Fig. 1 Mona Lisa
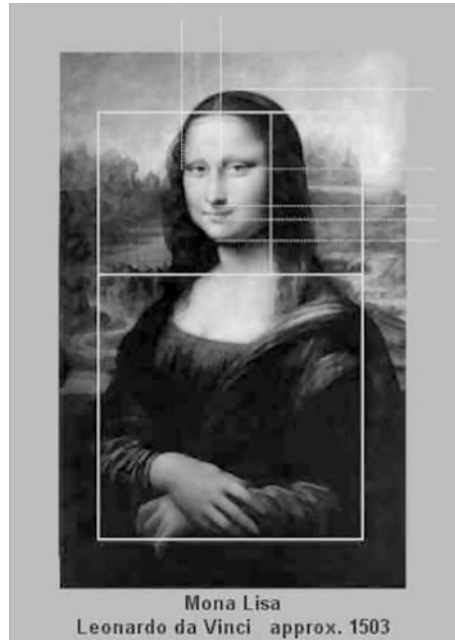
In Asia, the Golden Ratio proportions were employed in the building of the Taj Mahal, one of the Seven Wonders of the World. In Canada, the CN tower is a major example of the Golden Ratio in architecture as the ratio between the observation deck and its total height is exactly 1.618 [6]. Some argue that the phenomenon of Phi in nature is an accident while others sternly believe that it is apparently to add aesthetic appeal.

The phenomenon of ϕ also exists in art. As represented by the "Mona Lisa" by Leonardo Da Vinci, the phenomenon of ϕ is present in other works as well. Many of Da Vinci's famous paintings, including "The Last Supper," contain the Golden Ratio, as in the Renaissance period, Phi was known as the Divine Proportion. Other works such as "The Creation of Adam" by Michelangelo, "The Birth of Venus" by Botticelli, and "The Sacrament of Last Supper" by Salvador Dali accurately reflect the Golden Ratio.

3 Sample

Twenty-eight students from the Visual and Image Processing and the Climate Science classes of the Summer Ventures in Science and Math Program participated in the experiment. Due to the fact that this study was conducted at a high school level summer camp, the available resources were limited, especially with the number and
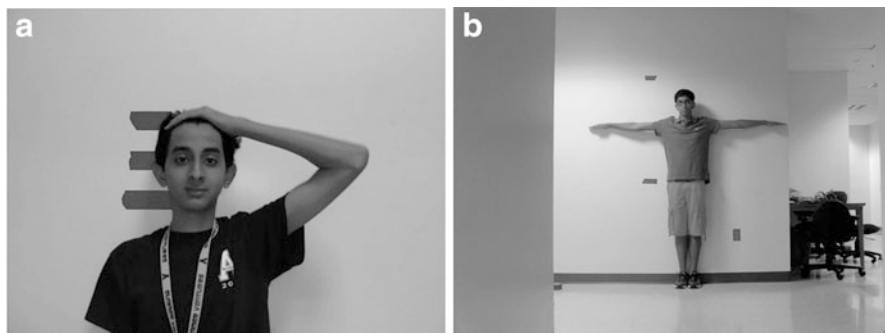
Fig. 2 (**a**) Face shot, (**b**) full body shot

demographics of the subjects. Nevertheless, 14 girls and 14 boys volunteered to participate in the study.

A full-face picture with the hair pulled back and behind the ears and a full-body picture with arms out and feet together was taken for each student. As demonstrated by Fig. 2a, blue tape was used to measure out 10 cm in the face shot. In Fig. 2b, the full body shot, the blue tape represents 1 m. This was done so a scale could be set on ImageJ to determine measurements from photos. ImageJ is a Java-based image-processing program developed at the National Institute of Health (http://imagej.nih.gov/ij/docs/intro.html). With ImageJ's user-written plugin accessibility, it is possible to solve many image processing and analysis problems via different toolboxes. The students' arm span, height, head height, head width, forehead height, and lower face lengths were measured using ImageJ. For the purpose of our experiment, forehead was defined as the area between the hairline and the eye level, the lower face was defined as the distance between the eye level and chin, and head width was measured from the widest point on the face.

People from four different racial backgrounds were present in the sample, but South Asians and Caucasians were dominant in the selected sample. The subjects were separated by race because of different genetic backgrounds. Based on information collected, ratios between different signature measurements can be discovered and used to find defining characteristics of gender and race.

4   Body Characteristics

4.1   Arm Span vs. Height

Figure 3 shows the correlation between arm span and height. Each point represents one subject from the study. The trend line has a slope of 0.7546 and an R^2-value of 0.7799. Since the R^2-value is close to one, it can be concluded that there is a

Arm Span vs. Height

$y = 0.7546x + 44.501$
$R^2 = 0.77988$
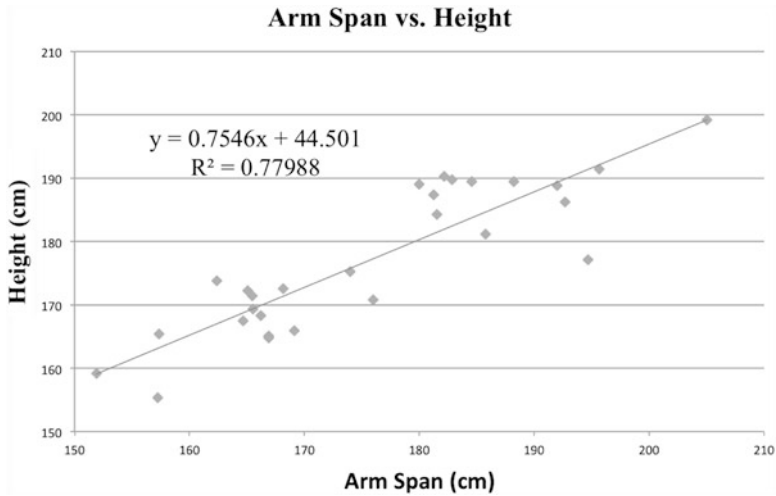
Fig. 3 Arm span vs. height

significant correlation between arm span and height. As seen by our trend line and scatter plot, very little variation is seen around the line of best fit, meaning that the line of best fit matches the data points fairly well. Additionally, a slope p-value of 0.000 indicates that the results are statistically significant. It may be noted that the typical p-value level for statistical significance is 0.05 or less. Thus, arm span and height indeed do have a significant correlation.

4.2 Head Width vs. Head Height

Figure 4 shows the correlation between head width and head height using data from all participants. The slope of the line of best fit is close to one; however, the R^2-value looks small. In this case also, the slope p-value is 0.000, indicating that this correlation is statistically significant as well. The low R^2-value may be due to some outliers towards the lower far right. It is also imperative to keep into consideration that the sample of 28 students for this study was small therefore not providing sufficient reliability.

4.3 Gender Averages

In Fig. 5, the graph compares the male, female, and overall average of arm span, height, head width, head height, forehead height, and lower face measurements. The averages for facial measurements do not differ greatly between the two genders.
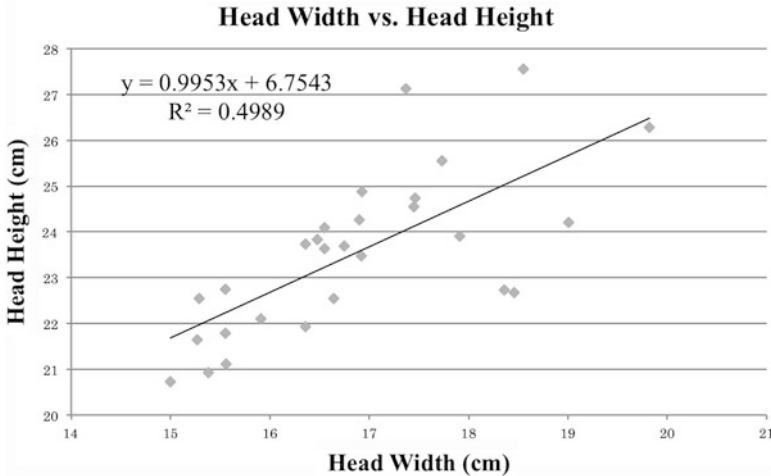
Head Width vs. Head Height

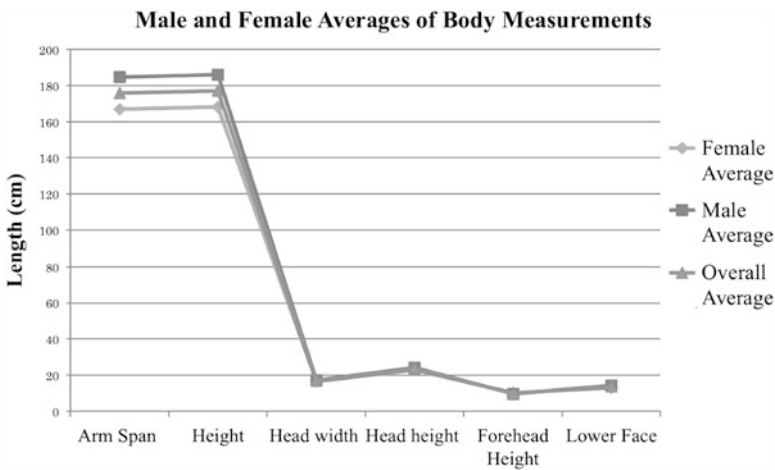$y = 0.9953x + 6.7543$
$R^2 = 0.4989$

Head Height (cm) [vertical axis]

Head Width (cm) [horizontal axis]

Fig. 4 Head width vs. head height

Male and Female Averages of Body Measurements

Length (cm) [vertical axis]

Female Average
Male Average
Overall Average

Arm Span   Height   Head width   Head height   Forehead Height   Lower Face

Fig. 5 Gender averages of body measurements

However, the largest difference among male and female averages is arm span and height. The purpose of adding arm span average and height average is to determine whether a correlation between the two exists as hypothesized. For this same reason, the other four averages are added. In essence, the comparison is being made between three pairs, not all six of the measurements. According to the data collected in this experiment, female subjects have a lower average arm span and height than those of the male subjects.
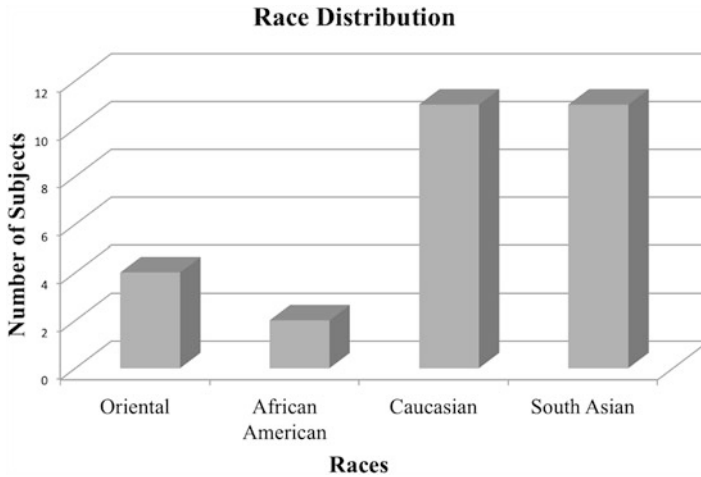
Fig. 6 Race distribution

5 Race Distribution

Figure 6 shows the distribution of participants in the experiment by race. A large majority of the students who were sampled were Caucasian and South Asian. Because this study was conducted at a summer math and science program, the number of South Asians in the study is on expected lines, as historically, South Asians are more interested in math and science as opposed to other subjects [4]. There were fewer Orientals and African Americans among the subjects who participated in this experiment. The term Orientals refers to people from East Asia. This is important to keep in mind when analyzing the data on this experiment because a larger sample size of Orientals and African Americans could have improved the experiment and produced more generalized conclusions.

5.1 Arm Span vs. Height

Figure 7 illustrates the comparison of arm span and height, separated by the four different races present in this study. The data collected in this experiment indicates that African Americans often have larger heights and arm spans. Caucasians had the shortest arm spans and heights, while South Asians had arm spans and heights that were most similar in length. However, as it is evident, the data are heavily skewed because the number of African Americans included in the study was not proportional to the number of Caucasians, Orientals, and South Asians in the study.
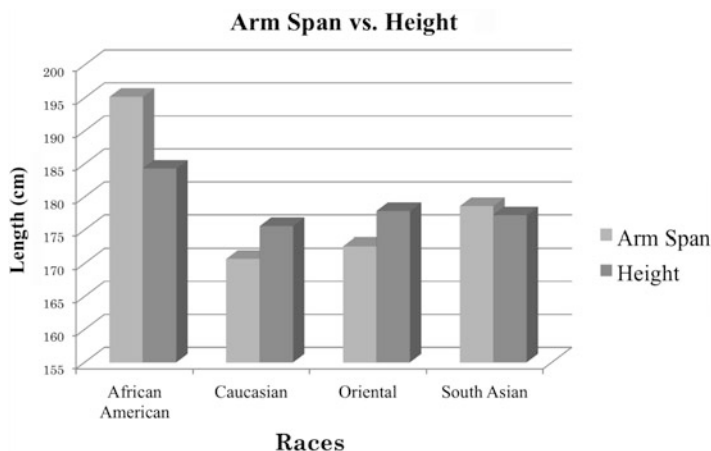
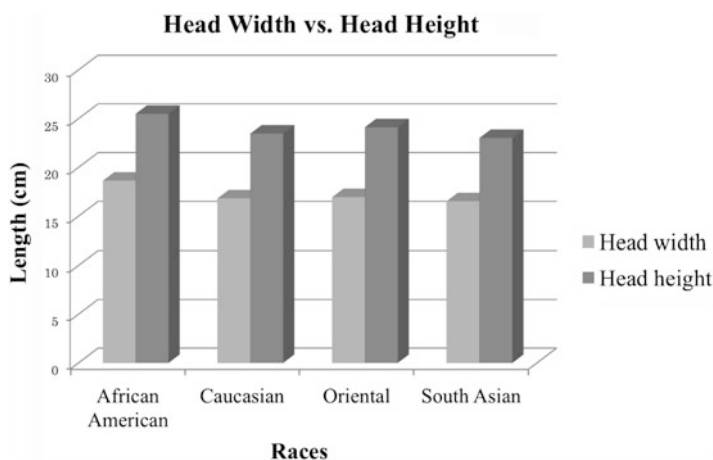**Fig. 7** Arm span vs. height

Fig. 8 Head width vs. head height

5.2 Head Width vs. Head Height

Figure 8 compares head width with head height separated by race. A consistent trend of larger head heights than head widths was observed in all four racial groups. However, the data in this study shows that African Americans in our study on average had bigger head heights than the other races present in the study. However, not much significance can be attached to this observation since the number of African American participants in the study was very small. It was also observed that the Caucasians in the experiment had a slightly smaller head height. The head
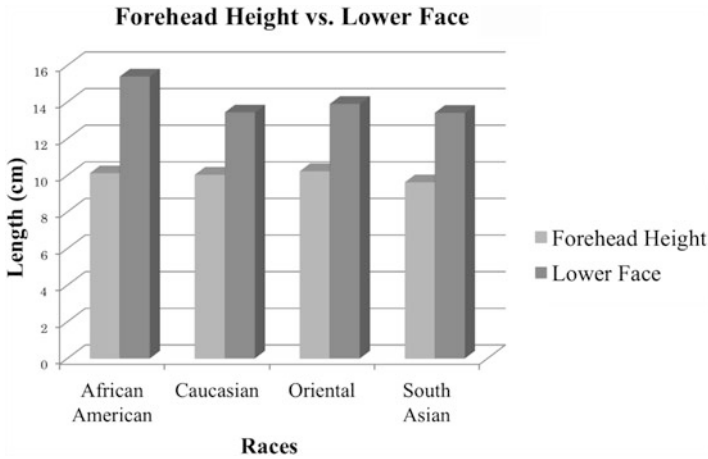
Fig. 9 Forehead height vs. lower face

heights vary from 22 to 25 cm and the head widths vary from 15 to 18 cm. Again, the data are heavily skewed; hence, a general conclusion is difficult to make.
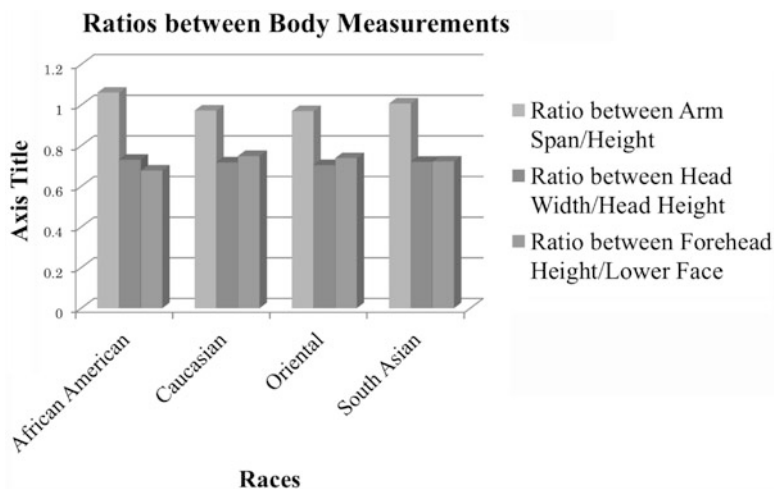
5.3 Forehead Height vs. Lower Face

Figure 9 demonstrates the comparison between forehead height and lower face length, separated by the four races. Using the data collected in this experiment, it can be concluded that African Americans tend to have larger lower faces, while Orientals tend to have larger foreheads.

When analyzing the data, an interesting peculiarity became evident. In Figure H, arm span vs. height, African Americans on average had a greater arm span than height. However, the other races had a greater height than arm span. In the other two graphs, the head height and lower face length were dominant over head width and forehead height for all races. Also, the African Americans stood out in the arm span vs. height graph, as their ratio did not correlate with the ratios of the rest of the races. This was interesting for more extensive study; however, because only two African Americans were involved in this study, it was highly skewed. If each race were represented equally, with a larger sample, the results and ratios would be more reliable.

5.4 Ratios Between Body Measurements

Figure 10 portrays the three different ratios comparing arm span with height, head width with head height, and forehead height with lower face length. In general, the ratio between arm span and height is very close to one in all racial groups.

Fig. 10 Ratios between body measurements

However, the ratio between head width and head height and the ratio between forehead height and lower face length is closer to 0.7. Orientals have shorter arm spans in comparison with their height. South Asians have almost the same ratio for head width and head height as forehead height and lower face. It is important to stress that the ratio for African Americans is larger than one but this cannot be statistically proven, as there were only two African American subjects in the study.

Conclusion

The female average of the ratio between the forehead height and the lower face is 0.7897. On the other hand, the average male ratio for the same criteria is 0.6739. A t-test shows that females have a higher average ratio than males (one-sided p-value 0.000). As mentioned above, a p-value of 0.05 or less indicates that the results are statistically significant. The initial goal of this experiment was to test whether it was possible to have someone with the Golden Ratio, i.e., aesthetically as pleasing as Mona Lisa. Unfortunately, there was a large discrepancy between the data set and the Golden Ratio. In this experiment's data set, the closest ratio to the Golden Ratio was 0.8774, which is still only about half of the Golden Ratio. A 95 % confidence interval for the mean ratio in the sample, with all subjects included, turns out to be (0.6975, 0.7661), indicating how unrealistic Mona Lisa's ratio is.

Similar results were also observed from the conclusions of the study done by Ricketts [10], supporting that the Golden Ratio is not common in humans and is therefore only an artistic and architectural concept. Moreover,

in another study conducted by Mos et al. [9], similar conclusions were reached as they found that even professional models did not resemble the Golden Ratio. Encompassing participants from different ethnical backgrounds, this study further acknowledges the fact that the Golden Ratio is indeed an ideal proportion for beauty.

In summary, it was concluded that nobody in the data set used in this experiment illustrated a close correlation to the Golden Ratio. However, when women are compared to men, it is obvious that they are more aesthetically pleasing as they have an overall average ratio that is closer to the Golden Ratio than men do.

References

1. Chhabra SK (2008) Using arm span to derive height: impact of three estimates of height on interpretation of spirometry. Ann Thorac Med 3(3):94–99
2. Farkas LG, Posnick JC, Hreczko TM (1992) Anthropometric growth study of the head. Cleft Palate Craniofac J 29(4):303–308
3. Hutton WC, Malko JA, Fajman WA (2003) Lumbar disc volume measured by mri: effects of bed rest, horizontal exercise, and vertical loading. Aviat Space Environ Med 74(1):73–78
4. Jo L (2012) Asian American college students' mathematics success and the model minority stereotype. Ph.D. thesis, Columbia University
5. Kopperdahl DL, Keaveny TM (1998) Yield strain behavior of trabecular bone. J Biomech 31(7):601–608
6. Livio M (2008) The golden ratio: the story of ϕ, the world's most astonishing number. Random House LLC, New York
7. Manonai J, Khanacharoen A, Theppisai U, Chittacharoen A (2001) Relationship between height and arm span in women of different age groups. J Obstet Gynaecol Res 27(6):325–327
8. Mohanty SP, Suresh Babu S, Sreekumaran Nair N (2001) The use of arm span as a predictor of height: a study of south Indian women. J Orthop Surg 9(1):19–23
9. Moss JP, Linney AD, Lowey MN (1995) The use of three-dimensional techniquesin facial esthetics. In: Seminars in orthodontics. Royal London Hospital Medical School, England, vol 1. Elsevier, pp 94–104. http://www.ncbi.nlm.nih.gov/pubmed/8935048
10. Ricketts RM (1982) The biologic significance of the divine proportion and fibonacci series. Am J Orthod 81(5):351–370