Original Article

A Computed Tomographic Study of the Bonwill Triangle for the Taiwanese Population

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Abstract

Purpose

The distances between the mandibular incisors and condyle or the distance between the right and left condyles are among the factors that affect the correct positioning of casts. Most dentists use the average value of the Bonwill triangle to position casts in an articulator if a face-bow is not used. However, there is some controversy as to whether the distance, as described by Bonwill, is consistent. The aim of this study, therefore, was to provide dentists with a reference value for the Bonwill triangle of the Taiwanese population for use in mounting casts in an articulator.

Material and methods

Ninety-nine computerized tomographic (CT) images of the heads of patients treated at China Medical University Hospital (48 females and 51 males; mean age: 40 years) were selected. The distance between the contact points of the mandibular central incisors' incisal edges and the central point of each condyle and the distance between the central points of both condyles were calculated using Mimics 10.01 software.

Results

The results showed that the distances between the mandibular incisors and the centers of the left and right condyles were 104 mm and 103 mm, respectively, while the distance between both condyles was 106 mm. Together, these distances approximately formed an equilateral triangle, as proposed by Bonwill, although the resulting triangle was slightly larger than that suggested by Bonwill. Also, while the length of the left side was slightly longer than that of the right side, the distance of both sides decreased with age above 30 years old, whereas the distance between the centers of the condyles increased with age until the age of 50 and then decreased.

Conclusion

This study showed that, among Taiwanese, the size of the Bonwill Triangle is larger for males and changes with age. The study also confirmed that the Bonwill triangle provides a feasible means of mounting casts in an articulator if a face-bow transfer cannot be employed.

Key words: Bonwill triangle, computerized tomographic (CT) images.

Introduction

An articulator is a mechanical tool for establishing the relationship between the upper and lower jaws outside the oral environment. The articulator simulates the patient's jaw movement and the position used by dentists to determine the occlusion of prostheses[1-3].

The Bonwill triangle was defined as a four-inch equilateral triangle with two sides connecting the contact points of the mandibular central incisors' incisal edges (or the midline of the mandibular residual ridge) to the midpoint of each condyle and one side connecting the condyles to each other. It was also suggested that the cusp angulation for complete dentures could be influenced by the size of this triangle. The Bonwill triangle was first described by William Gibson Arlington Bonwill in 1858, based on measurements of 6,000 skulls and 4,000 living persons. According to Bonwill, the length of each side, with few exceptions, is equal to 4 inches. However, various researchers have argued against the symmetry and correctness of the proposed figure. For example, Maggetti et al. used three-dimensional (3D) cone beam computed tomography (CBCT) scans of 120 arbitrarily selected individuals and found that the mean arm length of the Bonwill triangle was 103.3 mm, with a range of 90.2 mm (minimum) to 117.9 mm (maximum), and that the mean base length was 99.6 mm, with a range of 85.2 mm to 112.6 mm. There was a high correlation between the length of the left and right arms, but not between the arms and the base.

Although the theory of the average Bonwill triangle is often used in mounting casts to an articulator, significant occlusion errors in full mouth reconstruction cases have frequently been found. In such cases, the occlusion is complex and requires time-consuming adjustments. The consistency of the occlusal relationship of the cast in an articulator with that of the casts in a patient's mouth is affected by many factors, such as the 3D position of the casts, the choice of the anteroposterior reference point, the condylar and Bennett's inclinations, etc. Scholars have discussed these factors but have been unable to reach definite conclusions about them, and the average value of the Bonwill triangle has not been widely explored by measuring CT images for different ethnicities.

This study used CT images to measure the distances between the incisors and both condyles of the mandible and the distance between both condyles. The aim was to provide dentists with a reference value for the Bonwill triangle of the Taiwanese population for use in mounting casts in an articulator.

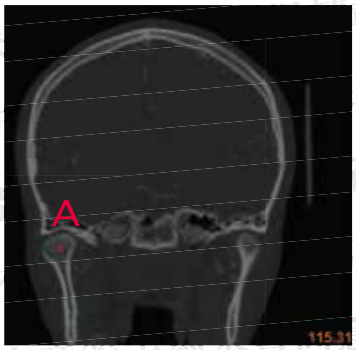
Material and methods

This study used CT images to measure the distances between the incisors and both condyles of the mandible and the distance between both condyles. The aim was to provide dentists with a reference value for the Bonwill triangle of the Taiwanese population for use in mounting casts in an articulator. The CT images were obtained (Light Speed, General Electric, Milwaukee, WI, USA) with the following technical parameters: 1.25-mm increments, 120 kV, 300–400 mAs, 240-mm field of view, and 512 × 512 pixels. All of the CT images were obtained between December 2007 and July 2009. The ethical issues of this study were approved by the institutional research board of China Medical University and Hospital. The measurements of the lengths between designated points were made according to the protocol described by Wu et al[4]. Briefly, before measuring, the coordinate system of each head was created in professional medical imaging software (Mimics 10.0, Materialise, Leuven, Belgium) using the "reslice" function, where the head was rotated first in the Frankfort horizontal (FH) plane parallel to the horizontal plane, followed by continued rotation with the head centered on the midsagittal plane of the image perpendicular to the FH plane (making the head face the anatomical frontal view). The coordinates of the slices in the frontal planes containing the longest condylar length were selected first and adjusted to coincide with the midpoint of the widest condylar width in the horizontal plane as points A and B shown in (Fig. 1). Meanwhile, the point where the mandibular central incisors first contacted in the horizontal plane is shown as point C in (Fig. 1).

The average values of the lengths between the lower incisor and condylar joint (IC-R and IC-L) and the right and left joints (C-LR) were calculated using the coordinates determined for the aforementioned 3 points. The distance between any two points in space was calculated using the formula shown below:

$$d \overset{\text{def}}{=} \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

Data were analyzed using the t-test and Wilcoxon signed-rank test in order to make comparisons between genders and the ANOVA and Kruskal-Wallis tests in order to make comparisons among age groups.



Coordinate:
X- 70.04, Y-124.45, Z-110.69

Coordinate:
X-180.18, Y-121.17, Z-111.83

Coordinate:
X-70.01, Y-124.89, Z-111.38

Coordinate:
X-180.31, Y-121.63, Z-112.00

Coordinate:
X-119.18, Y-65.97, Z-60.13

Fig. 1. Determinations of three points. A and B: midpoints coinciding both in the frontal and horizontal planes with the longest length and widest width. C: the point where the mandibular central incisors first contacted in the horizontal plane.

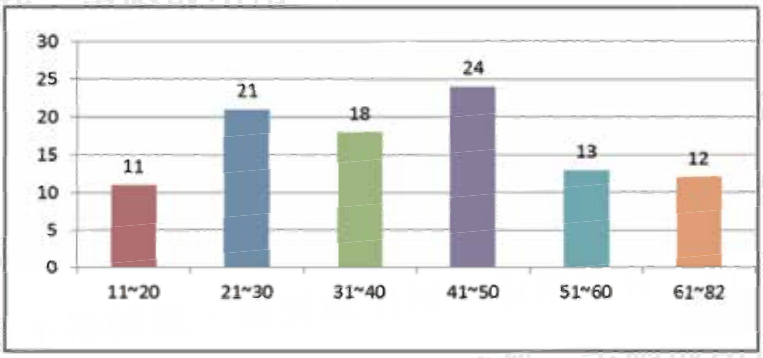


Fig. 2. Distribution of participants in different age groups.

Results

CT images from 99 Taiwanese subjects between 11 and 82 years of age, including 48 females and 51 males with a mean age of 40 years, were selected. The age distribution of the participants is shown in (Fig. 2). The measured lengths of the three sides of the Bonwill triangle for men and women, respectively, are shown in Table 1. The overall mean distance between the lower incisor and the center of the left condyle was 104 mm (IC-L; male: 107.3 mm; female: 100.6 mm), while that between the lower incisor and the center of the right condyle was 103 mm (IC-R; male: 106.1 mm; female: 100 mm). The differences between males and females for both the IC-L and IC-R were approximately 6 mm, with these differences being statistically significant.

The overall mean distance between the condyles on both sides (C-LR) was 105.9 mm. The difference between males (108 mm) and females (103.8 mm) was approximately 4 mm, with this difference also being statistically significant.

The measured lengths of the three sides of the Bonwill triangle for different age groups are shown in Table 2. The average measured lengths of the three sides of the Bonwill triangle in these Taiwanese subjects were roughly consistent with Bonwill's proposed equilateral triangle, although the lengths were 2 mm longer, on average, than the 4-inch sides proposed by Bonwill. The results of this study also indicated that the size of the Bonwill triangle changes with age.

While the mean triangle for these Taiwanese subjects was close to an equilateral triangle, the length of the left side was slightly longer than that of the right side (104 mmvs103 mm), although both of these distances decreased with age above the age of 30 (by about 1 to 2.5 mm per decade). In contrast, the length between the center points of both condyles increased with age until the age of 50 (from 101.9 mm to 107.8 mm), and then decreased (by about 1 to 1.4 mm per decade).

Table 1. Measured lengths for the three sides of the Bonwill triangle for males and females.

Sides	Gender	N	Mean ± SD	Median (Q1-Q3)	p-value[1]	p-value[2]
IC-L	F	48	100.62 ± 5.25	100.35 (97.52-103.23)	<.0001	<.0001
	M	51	107.32 ± 6.17	106.92 (103.86-111.68)		
IC-R	F	48	99.99 ± 4.97	99.74 (97.10-102.70)	<.0001	<.0001
	M	51	106.09 ± 6.16	105.35 (102.05-110.05)		
C-LR	F	48	103.82 ± 4.84	104.07 (100.70-107.71)	<.0001	0.0001
	M	51	107.96 ± 5.09	108.33 (104.25-110.74)		

* [1] t-test [2] Wilcoxon signed-rank test.
* IC-L: the length between the lower incisor andthe left condylar center; IC-R: the length between the lower incisor andthe right condylar center; C-LR: the length between the right and left condylar centers.

Table 2. Measured lengths for the three sides of the Bonwill triangle for different age groups.

Sides	Age	N	Mean±SD	Median (Q1-Q3)	p-value[1]	p-value[2]
IC-L	20 and below	11	101.60 ± 8.02	103.86 (92.45-106.98)	0.0041	0.01
	21-30	21	107.82 ± 7.28	106.89 (102.91-112.54)		
	31-40	18	105.50 ± 6.26	104.39 (100.86-109.13)		
	41-50	24	104.33 ± 5.70	104.83 (100.39-108.32)		
	51-60	13	101.97 ± 3.58	102.02 (99.62-103.80)		
	61and above	12	99.43 ± 5.40	99.07 (96.03-101.78)		
IC-R	20 and below	11	101.40 ± 7.40	102.07 (96.53-104.81)	0.0228	0.0793
	21-30	21	106.59 ± 6.87	105.35 (103.00-111.31)		
	31-40	18	104.51 ± 6.81	102.42 (98.67-107.58)		
	41-50	24	102.50 ± 5.37	102.31 (97.91-106.36)		
	51-60	13	101.60 ± 3.39	101.92 (99.87-103.91)		
	61 and above	12	99.54 ± 5.88	100.22 (98.69-102.02)		
C-LR	20 and below	11	101.88 ± 6.35	102.64 (98.72-104.25)	0.085	0.088
	21-30	21	105.73 ± 4.45	106.67 (104.23-108.80)		
	31-40	18	106.35 ± 6.25	107.09 (100.65-110.25)		
	41-50	24	107.79 ± 5.06	107.13 (105.04-110.26)		
	51-60	13	106.38 ± 5.20	105.41 (101.24-109.52)		
	61 and above	12	105.36 ± 3.90	106.29 (101.62-108.69)		

* [1] ANOVA [2] Kruskal-Wallis test
* IC-L: the length between the lower incisor andthe left condylar center; IC-R: the length between the lower incisor andthe right condylar center; C-LR: the length between the right and left condylar centers.

Discussion

Even as Bonwill's triangle theory remains controversial and various studies have reported different lengths for the different sides of the triangle, relevant data for Asian populations is still lacking[5]. The aim of this study, therefore, was to provide basic data for an Asian population and compare it with the values originally proposed by Bonwill. The average measured lengths of the 3 sides (104 mm for the left side, 103 mm for the right side, and 106 mm between the condyles on both sides) for the Taiwanese subjects in this study formed an approximately equilateral triangle and thus confirmed the validity of Bonwill's triangle theory to some extent. However, the size of the formed triangle was larger than that of the triangle originally proposed by Bonwill, who proposed that the length of each side length should be equal to 4 inches (101.6 mm). Maggetti et al. used cone beam computed tomography (CBCT) scans of 120 arbitrarily selected individuals and found that the mean side length of the Bonwill triangle was 103.3 mm, with a range of 90.2 mm (minimum) to 117.9 mm (maximum), and that the mean base length of the triangle was 99.6 mm, with a range of 85.2 mm to 112.6 mm[6]. The lengths from the mandibular central incisors to both the left and right condyles were close for both studies, but there was a difference of 6 mm for the length between both condyles. This might be due to differences in the head form among people of different ethnicities. For example, among Taiwanese people, the head form is more brachycephalic[7]. Therefore, the triangle formed in the study by Maggetti et al. was closer to being isosceles in shape, while the triangle formed in this study was closer to being equilateral in shape.

There were statistically significant differences in the side lengths of the formed triangle between the male and female subjects (IC-L: 107.32 ± 6.17 vs.100.62 ± 5.25; IC-R: 106.09 ± 6.16 vs. 99.99 ± 4.97; C-LR: 107.96 ± 5.09 vs.103.82 ± 4.84), as shown in Table 1. The overall difference in the sizes of the formed triangles might be attributed to fact that females are generally smaller in terms of body size than males.

The observed tendency toward increased side length with increasing age is in accordance with the downward and forward development of the face. However, it is interesting to note that the lengths between the mandibular incisors and both condyles began to decrease in middle age.

An articulator simulates the movement of the lower jaw and monitors the contact relationship of the teeth. Articulators can mainly be divided into the simple, semi-adjustable, and fully-adjustable categories. There is no consensus as to which category is the best because a more complex process may result in sources of error. Clinicians should thus choose suitable articulators according to the specifics of different cases in order to achieve the best and most predictable treatment results.

Nowadays, the use of a semi-adjustable articulator is recommended for most clinical cases given that these articulators are typically reasonably priced, provide sufficient clinical functions, allow for face-bow transfers, and are easy to use. The different positions of casts mounted in an articulator may change the moving distance, such that different motion patterns might occur. The posterior occlusal morphology and depth of the cingulum for anterior teeth may also be changed. During chewing and swallowing, the teeth will come into contact at and around the center of the occlusion position. If the occlusal contact is not smooth or is obstructed, it would cause occlusal interference. Relatedly, if a clinician is negligent in carefully and cautiously adjusting any occlusal interference, the occlusal interference may be a possible causative factor of temporomandibular joint syndrome symptoms such as headache, joint pain, and muscle pain.

When it is necessary to use the average values of the distances between the joints to mount the casts, we should simulate intraoral conditions to the extent possible in order to achieve the required occlusal coordination[8-13]. The mandibular occlusal morphology in the posterior region suggests that the buccal and lingual groove placement should be more mesial clinically for Taiwanese people, as the results from our study showed a smaller triangle. This study provides information helpful to achieving 3 out of the 9 goals of biological occlusion mentioned by Becker 8: no interference between centric occlusion and centric relation, no balancing contacts, and no cross-tooth balancing contacts.

Conclusion

The results of this study showed that the average side length values of the formed triangle in Taiwanese people are roughly consistent with Bonwill's proposed equilateral triangle, although the lengths were 2 mm longer, on average, than the 4-inch sides proposed by Bonwill, and they also changed with age. If CT imaging technology was applied to provide better measurement results, the positioning of casts in articulators may be more accurate. Dentists will then be able to increase the usage of articulators and improve the quality of the care they provide.

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