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Design of Bristle Shapes using 3-dimensional Teeth Data for the Periodontally Involved Patients

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Abstract

Bristles for the prosthetic and periodontally involved patients are investigated based on previous studies. Specifically, the ideal location and dimensions of bristles for the patients who were installed with fixed prostheses and severely involved periodontitis were investigated. 3D (Three-Dimensional) scanner was used to develop 3D visual models of bristles and teeth. These models were used for designing the ideal bristles. In the design, the interproximal area of dental arch and bristle must be maximized and the standard teeth may have to be chosen from many gypsum molds. During the design process,the factors that influence plaque removal by the bristle were considered.

Key words : Periodontal Disease, Toothbrush, Plaque, 3D scanner, Shape Design, Curve Fitting

I. INTRODUCTION

Among the many reasons that people lose their teeth normally, dental caries is the main reason when we are young but after mid-age, periodontal disease becomes the most important reason. The main cause of dental caries and periodontal disease is plaque, the bacterial substance which remains in the oral cavity. There are many methods to eliminate this plaque but brushing teeth is the most effective and convenient way.(1)

The factors that affect plaque removal by brushing are method of brushing, the shape of the toothbrush, and the material, length, diameter, arrangement, and number of the toothbrush's hair etc.(2)

Regarding the shape of the toothbrush,the hair of the existing toothbrush is rectangular. because this shape helps to clean the occlusal surface, which has a self-cleaning ability and thus does not need to be cleaned by brushing , unlike the smooth surface of tooth, buccal surface and palatal surface, which are used when chewing foods. Therefore, it could not help removing the foods and plaque stuck in the interproximal area and gingival sulcus.(3)

Toothbrush cannot always clean the surface of all the teeth evenly. The Incisor is best cleaned, and then, Canine and Premolar and Molar, the worst cleaned. The buccal surface, in particular, is better cleaned than the palatal surface and the mesial surface better than the distal surface. It is difficult to brush the interproximal area and between teeth and the gingival sulcus. Furthermore, the plaque between the lower molar and the interproximal area of lingual surface is the most difficult to remove.(4)

Although there are many important factors when designing toothbrush for removing plaque, we decided the shape of toothbrush's hair as the main factor in this study. When the hair's shape is designed, the curved surface of teeth needs to be measured, but this is not easy because the shape of teeth varies from people to people and is very complicated. Therefore, the optimum hair shape of toothbrush was determined after the curved line of the complicated tooth was obtained by a using 3 dimension scanner.

Recently, the 3D scanner technology has been studied and developed. Because the 3 D scanner can reproduce the exact shape of measured object , it saves the time required for modeling, which was done by hand in the past, and it has been used for redesigning, analysis and inspection in reverse engineering.(5) Moreover, the 3D technology has been applied to various fields, such as the medicine and dentistry.

Because the shapes of human organs and teeth are very complicated, specific shaping of a person's teethbesides general modeling was impossible. However, through exact

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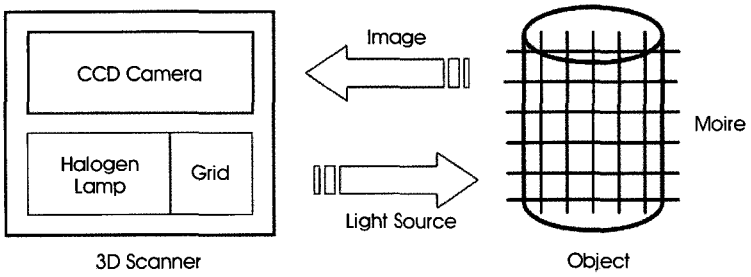

Fig. 1. Basic principle of 3D scanner.

measurements and modeling, 3D scanner canshow the exact shape, which is difficult to express manually. Because of this ability, 3D scanner technology is expected to be used in various forms in the medical and dentistry field in future. It can be useful for medical diagnosis and treatments and for construction of patient database. In dentistry, a few 3 D scanner companies are developing commercial systems and their application is expected to beunlimited as long as dentists are willing to embrace this technology.

By using a 3D scanner, we create a 3D model by measuring parts, whose plaque is the most difficult to remove bybrushing to make the optimum line use various approximate equation after sampling a sectioned line shape of the model and develop the optimum toothbrush for patients of dental ailments.

II. CREATION OF 3D TEETH MODEL

The 3D scanner applied for this study was non-contact style, and a halogen lamp was used for its lighting source. Its measurement method was PMP (Phase Measuring Profilomentry) which was part of Moare way.

A. Basic Principle of 3D Scanner.

After positioning the object within the suitable distance from scanner and the measurement area using a basic measurement method, scanning was performed. As shown in Fig. 1, when scanning started, the light from the lighting source was on the object, and this light went through the close lattice of the front of the lighting source of the inside scanner. Then, Moare pattern on object was made, and this pattern was input again as animage of the CCD (Charge-Coupled Device) camera, which was installed inside the scanner. The image of the object with the Moare pattern was duplicated with a square lattice in straight width and length, so it was able to find the angle of the lattice calculating phase succession. Then, the 3D scanner created points consistingof numerous x, y, z coordinates, the 3D data.[6]

B. Object for Measuring

The object measured in this study was the lingual surface of the lower molar, and Fig. 2 shows the inside of the mouth. The upper part was called maxillar, and the lower part was mandible. These parts became the object because removing the plaque between tooth and tooth, i.e, the inside of the mandibular molar, the interproximal area among the lingual surfaces, was the most difficult.

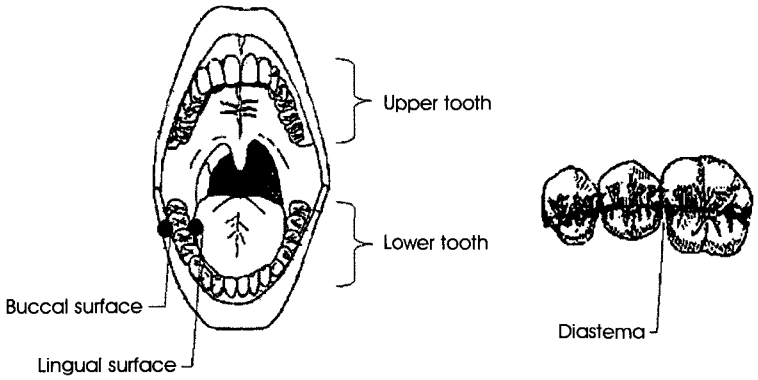

Fig. 2. Part of molar in mouth.

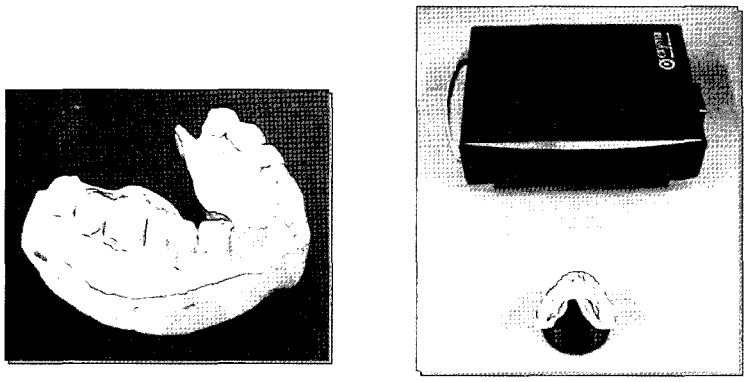

Fig. 3. Plaster cast of teeth and 3D scanner.

The gypsum model of the dental arch of a man in his 20's was chosen as the object for measurement, as shown in Fig. 3.

C. Measuring 3D.

We measuredthe lower molar area and lingual surface, the object of this study, by using the gypsum model of the chosen dental arch and with the constructed system. Rough scanning process was shown in Fig. 4. Fig. 4(a) shows the CCD camera image before measuring the object. If we measured with operation tool of the scanner, the measuring status was expressed in color as shown in Fig. 4(b), where the green color was the best measured area, followed by blue and then red. Fig. 4(c) shows the Morea pattern created by lighting source which passed through the lattice on the object. We were able to check the Morea pattern described previously. Fig. 4(d) was the first 3D model made in the scanner operation tool. The 3D scanner's spec used in this research represented in table 1.

D. Creation of 3D Model

The process of making the dental arch 3D model was shown in Fig. 5. The 3D scanner scanned the object and processed the scanned image and created the data.[7] The data created here were the coordinates of the 3D points of the measured object. The scanned data were used to make the 3D teeth model after

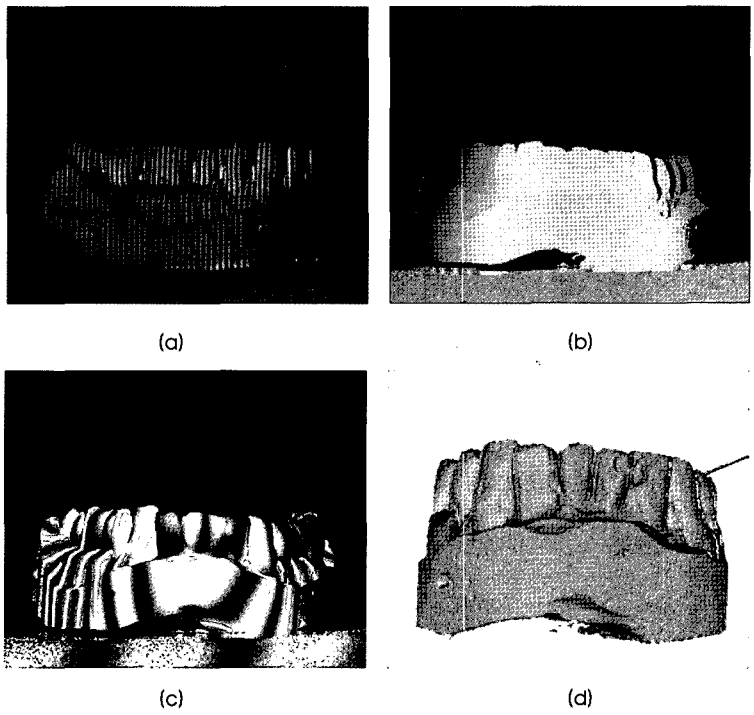

Fig. 4. Scan process. (a) CCD camera image, (b)image of scan area, (c) moire image, (d) 3D image.

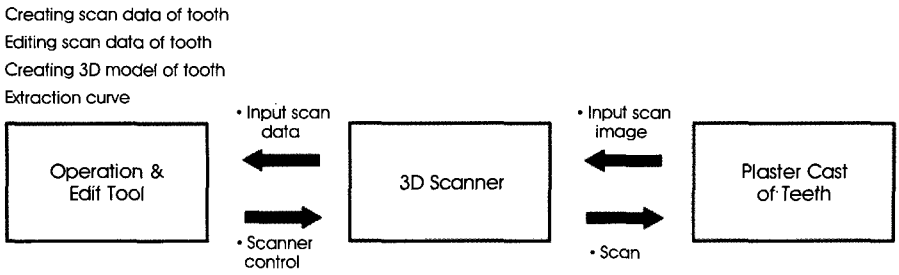

Fig. 5. Process of creating teeth model.

the editing process in the CATIA software (Ver.5, DASSAULT SYSTEMS, Suresnes, France). Fig. 6 shows the editing process of the data on the created point in CATIA v5. In Fig. 6(a), point data were imported into CATIA v5, and Fig. 6(b) was the process of sampling these points and eliminating noise. In Fig. 6(c), this became a polygon, and after filling the

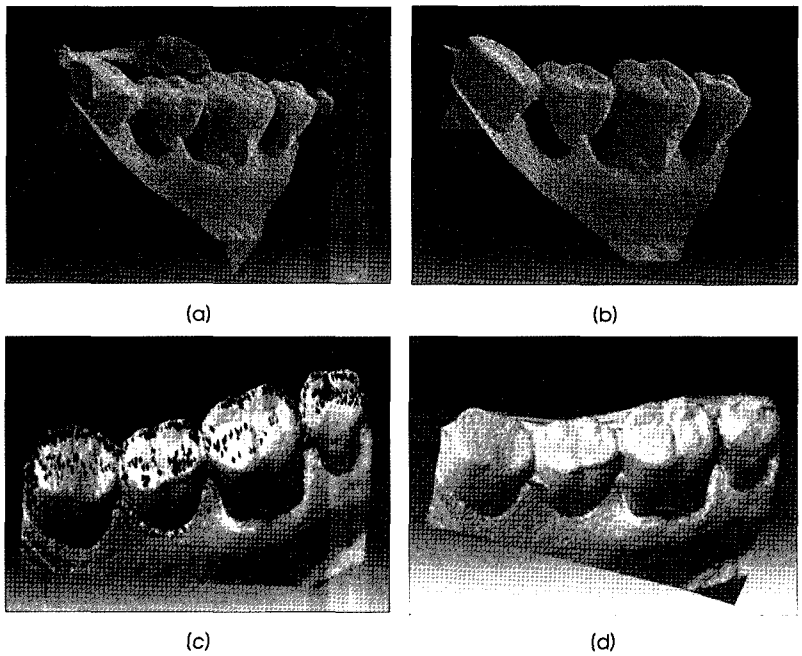

Fig. 6. Modeling process of teeth in CATIA v5. (a) import of scan, (b) removing noise and sampling scan, (c) fill-hole process, (d) final teeth model

Table 1. 3D Scanner Spec

	EXIMA-E100
Scanning Area(mm)	100×75×70
Scanning Time	Fast Mode(0.7sec)/Precision Mode(1.8sec) High Precision Mode(3.5sec)
Optimal Scanning Distance	800mm
Maximum Number of Data Points	300,000points
Operating Temperature	15℃-30℃
Scanning Method	MOIRE & PMP Method
Product Size	295mm×210mm×78mm
Product Weight	2.6kg
Camera Resolution	640×480pixels
Power	AC110 - 240V , 50Hz / 60Hz
Light Source	Laser Class II TypePC/OS

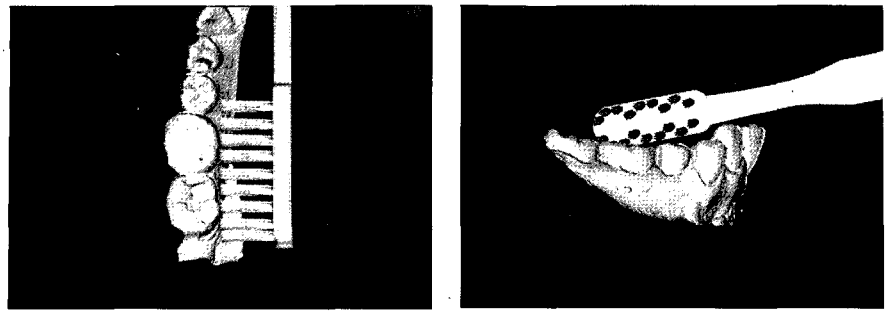

Fig. 7. 3D visualization toothbrush in market on teeth.

vacant space, a 3D model was constructed as in Fig. 6(d).

III. ANALYSIS OF THE CURRENT TOOTHBRUSH

When the toothbrush for a patient of periodontal disease was designed, the hair transplant shaping of the toothbrush suitable for the dental arch of the chosen standard teeth needed to be visualized in 3D, but above all, the toothbrush being sold at current needed to be analyzed. In the designing of a toothbrush, the toothbrush must be shaped suitable for the parts that were difficult to brush with the current toothbrush, so the weaknesses of the current toothbrush needed to be investigated before embarking on a new design. After this analysis, the checked problems could be applied to the new toothbrush.

After randomly choosing domestic or imported toothbrushes currently in the market, we collected data on their overall length, the length of the hair-planted part, the length of the neck part, and the width of the neck part, etc. After comparing and analyzing these acquired data, we directly applied to the lingual surface of the lower molar, the most difficult part to brush, then checkedtheir problems and found additional factors to be considered when designing a toothbrush for patients of dental diseases, and learned about more accurate hair position and their shape.

A. Measuring Samples and Finding Problems.

We measured the overall length of the toothbrush, the

Table 2. Specifications of toothbrushes made in Korea.

Products	L1	L2	W1	L3	L4	W2
Trowaway	183	24	8.5	17	66	4.6
Doctorsedoc1	181	26.8	10.5	16.8	59	5.2
Doctorsedoc2	193	29.7	13.3	16.8	60	4.8
Atman	193	30.7	13.8	16.7	69.2	5.4
Oxy Dental	192.5	34.6	13.5	15.7	69.6	6-8.8
Median	196	34	12.3	17.5	56	5.1
Crio	185	30.6	11.8	16	64.8	6-8.5
Dental 2080	189	29.4	12.6	17.6	70	5.7-10
Average	189.06	30.00	12.04	16.76	64.32	5.95

Table 3. Specifications of toothbrushes made in US.

Products	L1	L2	W1	L3	L4	W2
Butler409	160	27.4	11.3	17.8	43.2	6.7
Butler430	190	28.5	8.2	17	57	6
Oral-B	184	31.5	14	17	70.5	7-9
Oral-B	197	31.7	13.2	16	63.4	6-11
Colgate	161	28	7.4	16	48	5.2
Colgate	195	27.7	15	15	45	5.2
Average	181.17	29.13	11.52	16.47	54.52	6.65

Table 4. Specifications of toothbrushes made in Japan.

Products	L1	L2	W1	L3	L4	W2
V-7	177	26	7.2	15.5	28	3
Dr.Denti	185	28	11	16	34.5	5.8
Dent.EX.	165	20	6	14.2	60	4.7
Throwaway	162	25.5	9.5	15	60	5
Average	172.25	24.87	8.42	15.17	45.62	4.62

length and width of its hair-planted part, and the length and width of the curved part, etc of 8 kinds of domestic toothbrushes, 6 kinds of American, and 4 kinds of Japanese toothbrushes, which were selected among the products currently sold.

The measured data were provided in tables 2, 3 and 4, where L1 meant the toothbrush's overall length, L2 meant the overall length of the hair-planted part, W1 was the width of the hair-planted part, L3 the length of the hair part, L4 the length till neck part , and W2 the width of the neck part.

Domestic and American products gave limitation in movement inside the mouth due to their long hair-planted part, and it was difficult to use in brushing the lingual surface of the lower molar effectively because the thick neck part interrupts the front teeth. All of the Japanese samples weremostly short and especially, its neck part was thin, so brushing and cleaning the lingual surface of lower molar was not obstructed in any way, but its neck part was too short, so it gave limitations in movement inside the mouth.

Therefore, we learned that Korean and American toothbrushes had effective overall length and length of the neck part, whereas the Japanese toothbrushes had effective width of hair-plantedpart and neck part for brushing.

B. Visualize 3D of Existing Toothbrush.

The checked problems were visualized in 3D by modeling the existing toothbrush.

Fig.7 shows the visualization of the problem of hair shape and neck part of the existing toothbrush. The shape of existing toothbrush's hair was not effective for brushing the interproximal area. Likewise, the thick width of the neck part limited the user in their approach to the inside molar area interrupting the anterior tooth.

Ⅳ. CREATING CONJUNCT LINE ON THE SECTION OF TOOTH.

The line selected against a tooth section by 3D scanner and CATIA corresponds with the shape of actual teeth. Designing the shape of the hair according to the shape of this line was the most appropriate for the purpose of this study, but if we designed the shape of the hair according to the original shape, it would be very difficult to design and process because the shape of the teeth was too much complicated. Therefore, the conjunct line possible for processing should be made after making this shape similarly. As mentioned, the shape of the

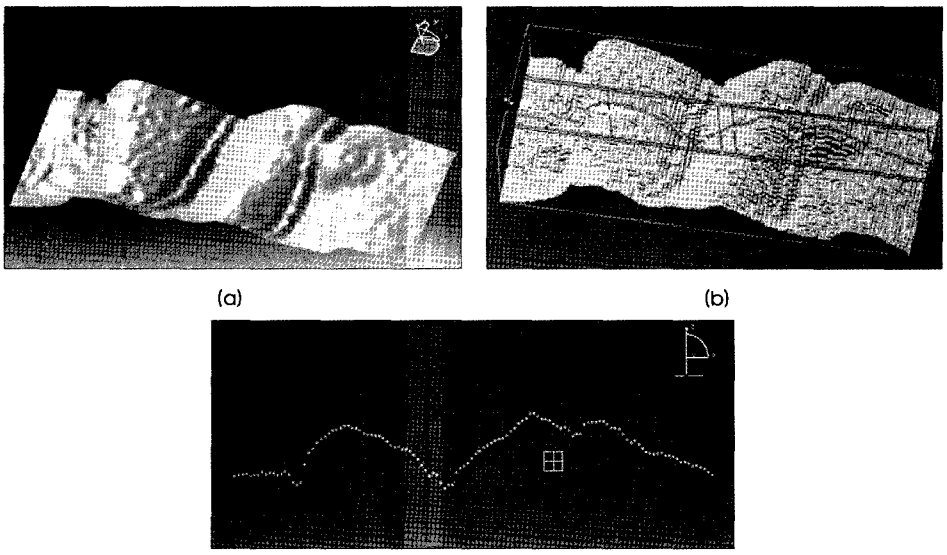

Fig. 8. Process of curve extraction. (a) Selection of part of tooth model, (b) Selection curve, (c) Curve extraction.

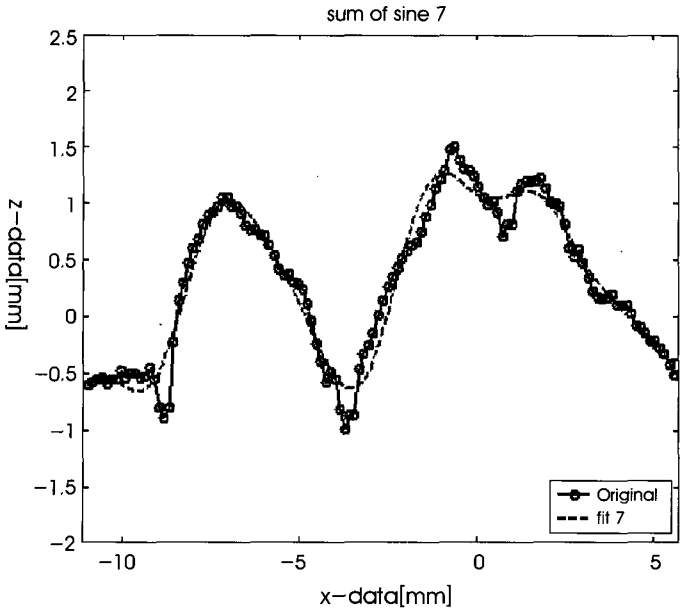

Fig. 9. Curve Fitting using sum of sine.

hair was determined by the lingual surface of the lower molar, which was the most difficult part to be brushed, because foreign material in interproximal area of other parts can be easily removed if we brush with this shape of the hair.

A. Selection of Teeth Section Line

To select the line for the chosen lingual surface of the lower molar, we used CATIA. In the case of a normal teeth section line, this line was not a straight line like that of a normal machine part, but it consist of complicated round lines, so we had taken the teeth shape using 3D scanner and after creating a 3D teeth model in CATIA, then selected a round line against the section of the lingual surface of the lower molar. Fig. 8(a) was the partial model for the necessary part used for the selection of the line in the created model of the lingual surface of the lower molar. If we selected points of sections shown in Fig. 8(b), a second line, which has x-z coordinates as shown in Fig. 8(c), would be selected.

B. Creation of Conjunct Line and Its Verification.

We had created conjunct line against selected line and verified the line. The conjunct line was made by using the following approximate equation, and this formula included the exponential function, Fourier series, sine sum, Gaussian, a polynomial expression, and rational expression. And the error was measured by using Sum Square Error (SSE) and Root Mean Square Error (RMSE) to verify the conjunct line. The suitability of this line was verified by using R-square and adjusted R-square.

As you can see from Table 5, the conjunct line using the exponential function, Fourier series, and Gaussian had a large error and poor suitability. The conjunct line using the polynomial expression, rational expression, sine sum had a small error and good suitability, and the optimum conjunct line was the sine sum. Fig. 9 showsthe conjunct line using sine sum.

Table 5. Evaluation of Curve Fittings.

Curve Fitting	Goodness of Fit			
	SSE	R-square	Adj. R-square	RMSE
Polynomial	4.986	0.909	0.902	0.209
Exponential	36.090	0.343	0.327	0.548
Fourier	15.450	0.664	0.624	0.410
Gaussian	12.670	0.769	0.716	0.356
Rational	3.757	0.932	0.926	0.182
Sum of Sine	2.859	0.948	0.938	0.167

V. DESIGNING OF TOOTHBRUSH SHAPE.

We created conjunct line against the selected teeth section line and applied this line to decide the shape of the toothbrush hair. Fig. 10 shows the shape of the toothbrush hair designed with the conjunct line. Fig. 11 shows the shape of toothbrush adjusted with the neck part, which was selected by analysis of existing toothbrush.

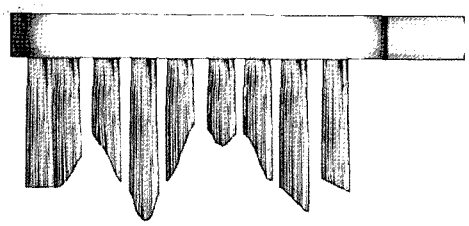

Fig. 10. Design of bristle using selected curve.

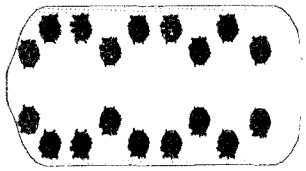

Fig. 11. Design of toothbrush's neck.

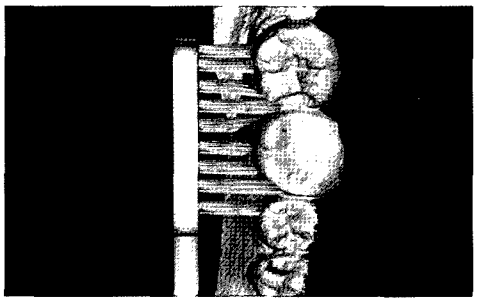

Fig. 12. Effectiveness of bristle shape.

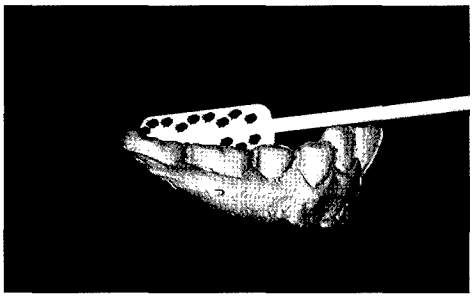

Fig. 13. Effectiveness of toothbrush neck.

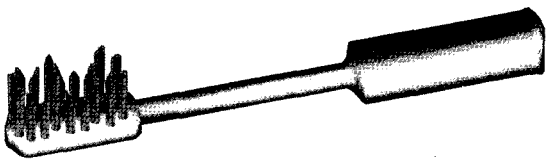

Fig. 14. Entire-view of toothbrush.

Wehave applied thetoothbrush designed the 3D teeth model. As shown in Fig. 12, this toothbrush hair was effective for brushing the interproximal area between tooth and tooth. And as shown in Fig. 13, dueto its small neck part, it had no problem in brushing the lingual surface of the lower molar. Fig. 14 shows the final shape of the toothbrush.

VI. DISCUSSION

In this study, before developing a toothbrush for patients of periodontal diseases, existing toothbrushes wereanalyzed and applied for the lingual surface of the lower molar, the most difficult part to brush, to identify the problems of these toothbrushes.

With a 3D scanner, we measured the lingual surface of the lower molar and created a 3D model. After selecting the section line of model, we applied various conjunct line methods and selected the optimum line, considering in future process.

Knowing the problems of the current toothbrush, we decided the widths of hair head part and neck part, and designed the shape of the brush hair by using the chosen conjunct line. The following conclusions are drawn.

1. To solve the problem of plaque removal, the main cause of periodontal diseases, the surviving foreign substance in the interproximal area, needed to be eliminated effectively, but after analyzing the existing toothbrushes, the shape of the toothbrush and the shape of toothbrush hair were found to be improper for brushing of the lingual surface of the lower molar, which is the most difficult to be brushed.

2. Because the shape of the teeth dental arch gypsum model, which was randomly selected, was very complicated, it was difficult to express this shape by use of the normal modeling method. Therefore, a 3D scanner was used to measure the teeth and its operation tool, and the measured data were used for removing pile hole and noise and then, the final 3D model were created.

3. After selecting the section line of the created model, we generated the conjunct line against the line selected by use of an approximate equation like Fourier series, sine sum,

Gaussian, a polynomial expression and interpolation, which all used the 3D data.

4. We decided on the designs of the neck part and hair-planted part of the toothbrush after checking the problematic points of existing toothbrushes and visualized the designs in 3D by adjusting them to the dental arch gypsum model, which was measured by a 3D scanner.

5. We designed the shape of toothbrush hair by using the selected conjunct line and designed a toothbrush for patients of dental diseases by adjusting the previously decided widths of the neck part and hair-planted part to the width of the hair of the toothbrush designed above.

This new toothbrush designed in this study will allow easy access to the interproximal area of the lingual surfaceof the lower molar, so patients can effectively remove the plaque around this area to prevent periodontal diseases.

Because the 3D scanner can provide exact information on the teeth, we can produce a toothbrush whose shape of the hair is suitable for the various shapes of people's teeth.

As a future research project, if we can verify the effectiveness of the toothbrush above after comparing the results of clinical demonstration in an actual dental clinic with the result from the use of an actually produced toothbrush, we can develop a production system for these personal toothbrushes that can prevent periodontal diseases.

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