Retentive Force of Pure Titanium Konus Telescope Crowns Fabricated Using CAD/CAD System

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The purpose of this study was to investigate the clinical application possibility of pure titanium konus telescope crowns fabricated using a CAD/CAM system. For the CAD/CAM system, Dental Cadim (Advance Co.) was used. For the material, exclusive pure titanium block for this system was used in this experiment. Two types of experimental dies with different heights assumed the konus inner crown and three types of konus outer crowns with different gap widths at the occlusal part were prepared. The outer crown was seated on the inner crown die, and a load was applied perpendicularly to the upper surface of the outer crown for 10 seconds. Pullout test was performed at a crosshead speed of 5 mm/min, and the retentive force was measured. With increase in the height of the inner crown die and the applied load, the retentive force of konus telescope crown increased. Similarly, as the gap width at the occlusal part between the inner crown die and outer crown increased, the retentive force of konus telescope crown also increased.

Keywords: Konus telescope crown, CAD/CAM system, Retentive force

INTRODUCTION

Recently, the CAD/CAM system has gained attention as the metal processing technique substitute for the conventional lost wax technique in dentistry. With time, the processing accuracy of the CAD/CAM system has remarkably improved owing to improvement and development of the measuring apparatus and processing machine. One ultimate benefit is that the fitting precision of crowns fabricated using the CAD/CAM system is drawing closer to that of the cast crown[1-4].

On the other hand, titanium is expected to use as a dental metal because of its excellent biocompatibility and corrosion resistance. The workability of titanium, which used to be one weak point of this metal, has been overcome by the development and use of the casting machine and exclusive dental investment material. However, some problems that easily produce casting defects still remain, such as blowholes by casting. In addition, a hard and fragile reaction layer is inevitably formed on the casting surface. Against this backdrop of problems that still plague titanium crowns fabricated by casting; an idea was hatched to fabricate konus telescope crowns by leveraging the inherent advantages on two fronts: the high-precision processing of CAD/CAM system and the biocompatibility of pure titanium.

For konus telescope crowns, the retentive force is achieved by wedge effect as the outer crown becomes slightly deformed. Therefore, a small gap at the occlusal part between the inner and outer crowns is absolutely required. Consequently, to make konus telescope crowns possess the appropriate retentive force by casting; advanced and precise technology is not only desirable, but absolutely necessary. In the mean time, the CAD/CAM system is suitable for manufacturing konus telescope crowns because the crown form can be computer-generated.

The purpose of this study was to examine the retentive force of pure titanium konus telescope crowns fabricated using a CAD/CAM system. First, a die which assumed the konus inner crown was constructed by processing the pure titanium block using the CAD/CAM system. Next, a konus outer crown was fabricated using the same material and machine. At this time, gap width at the occlusal part between the die and outer crown would be adjusted to a predetermined value. Then, the outer crown was seated on the die and after applying a specified load perpendicularly, pullout test was performed and the retentive force of the konus telescope crown was measured.

MATERIALS AND METHODS

For the CAD/CAM system, Dental Cadim (Advance Co.) was used to fabricate specimens for this experiment. For the crown material, exclusive pure titanium block for this system was used in this experiment.

Fabricating konus inner crowns

In the fabrication of experimental samples, pure titanium block was first processed using Dental Cadim to the end of fabricating an experimental die which assumed a konus inner crown. The die assumed the shape of a conical cylinder with the following dimensions: cervix diameter was 8 mm, axial taper angle was 6 degrees, and height was either 4 or 6 mm (Fig.
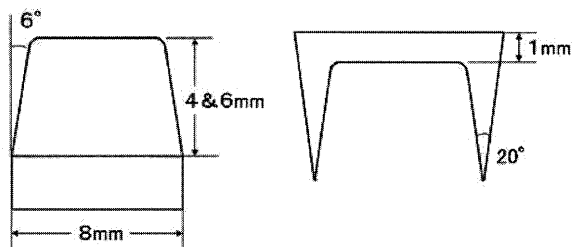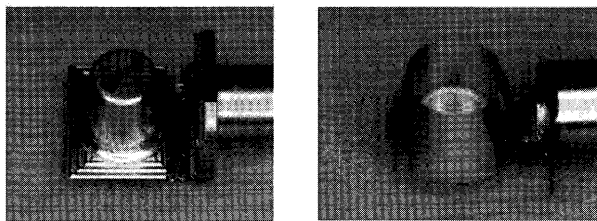
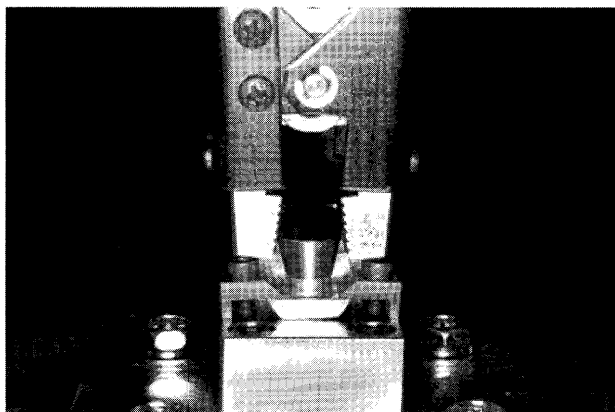Fig. 1   Experimental inner crown die and outer crown.

Fig. 2   Pullout test for retentive force measurement.

1). The corner crossing the occlusal surface and axial surface was rounded to 1 mm radius. For finishing processing of the die, two kinds of ball end mills with diameters of 2 mm and 1 mm were used at 20000 rpm/min. Following which, surface of the inner crown die was polished using a centrifugal shooting-type polishing machine from several directions for a total of two minutes.

Fabricating konus outer crowns
Next, a konus outer crown was processed using the same material and machine. The inside of the outer crown was fabricated in the same manner as the outside of the inner crown die. As for the height of the conical cylinder, it was set at 0, 50, or 100 μm taller than the original inner crown die; in other words, three kinds of outer crowns were thus prepared. Based on these dimensions, gap width at the occlusal

part between the die and outer crown was 0, 50, or 100 μm. Further, the outer crown was finished to a knife-edge margin with 20-degree angle, and thickness of the occlusal part of outer crown was set at 1 mm (Fig. 1). As for the inner surface of outer crown, it was left as it was processed without polishing. On the overall, six inner crown dies and six outer crowns were prepared for each experimental condition.

Measuring retentive force
To measure retentive force, three specimens out of six were tested. The outer crown was seated on the inner crown die. Then, a load of 50 N was applied perpendicularly to the upper surface of outer crown for 10 seconds using a desktop measurement apparatus (M-1356, Aikoh Engineering) and a push-pull gage (M-9520B, Aikoh Engineering). Next, pullout test was performed using a utility clip as shown in Fig. 2 at a crosshead speed of 5 mm/min and the retentive force was measured. Measurement was carried out five times for each specimen and the average value was calculated.

The other three specimens were tested using the same method, except that the applied load was changed to 100 N. This time, the mark was placed on the marginal part of specimen so as to fit the outer crown consistently in the same position to the inner crown die. Data were analyzed using two-way ANOVA in combination with Tukey's multiple comparison test.

After loading, some specimens were embedded in resin and then cut vertically in the center. The cross-sectional surface thus obtained was polished, and the gap at the occlusal part between the die and outer crown was observed using a stereomicroscope (Scopeman, Moritex).

RESULTS

Figure 3 shows the retentive force values of the pure titanium konus telescope crown when the height of inner crown was 4 mm. When the gap at occlusal part between the inner crown die and outer crown was 0 μm and the applied load was 50 N, retentive force showed a minimum value of 6.3 N. Then, as both the gap at occlusal part and the applied load increased, the retentive force of konus telescope crown also increased. When the gap was 100 μm and the applied load was 100 N, the retentive force reached a maximum value of 17.4 N. Statistical analysis revealed that there were significant differences in both factors of gap width at occlusal part and the applied load (p<0.01). However, according to Tukey's multiple comparison test, there were no significant differences between the gap widths of 50 μm and 100 μm when the applied load was 50 N.

Figure 4 shows the retentive force values of
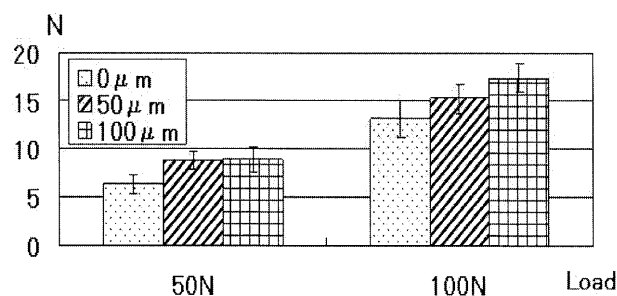
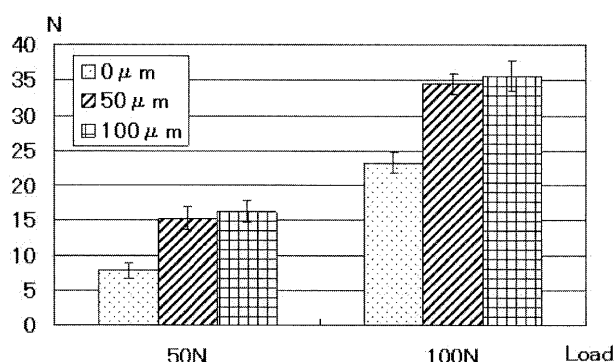Fig. 3　Retentive force values of konus telescope crown (4 mm height).

Fig. 4　Retentive force values of konus telescope crown (6 mm height).
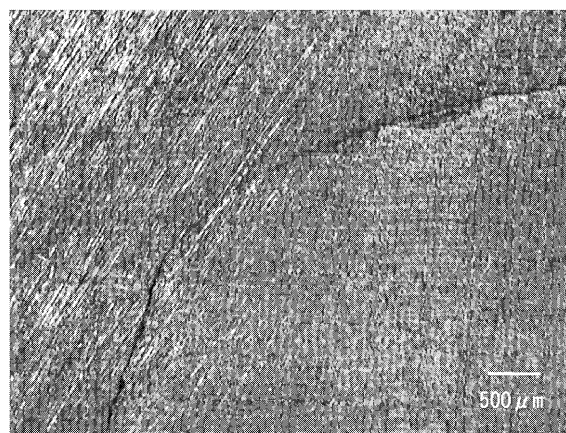

Fig. 5　Cross-sectional image of specimen with 4 mm height and 0 μm gap at occlusal part after 50 N loading.

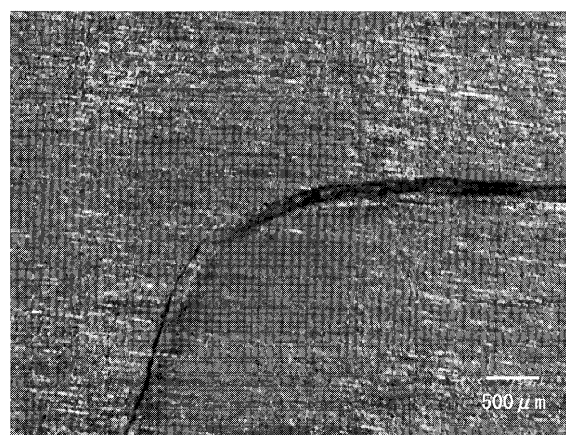Fig. 6　Cross-sectional image of specimen with 6 mm height and 100 μm gap at occlusal part after 100 N loading.

the pure titanium konus telescope crown when the height of inner crown was 6 mm. Similarly, when the gap at occlusal part was 0 μm and the applied load was 50 N, the retentive force hit a minimum of 7.8 N. Then, as both the gap at occlusal part and the applied load increased, the retentive force of konus telescope crown also increased. However, the retentive force values yielded were higher compared with those obtained when the height of inner crown die was 4 mm. In particular, when the gap was 100 μm and the load was 100 N, the retentive force reached a maximum value of 35.6 N. Statistical analysis revealed that there were significant differences in both factors of gap width at occlusal part and the applied load ($p < 0.01$). However, according to Tukey's multiple comparison test, there were no significant differences between the gap widths of 50 μm and 100 μm when the applied load was 50 N and 100 N.

Figures 5 and 6 show the typical cross-sectional images of the specimens after loading. When the height of inner crown die was 4 mm and the gap at occlusal part was 0 μm, application of 50 N load caused a gap of 20 μm gap to be observed in the occlusal area. Meanwhile, when the height of inner crown die was 6 mm and the gap was 100 μm, application of 100 N load caused a gap of about 180 μm to be observed in the occlusal area.

DISCUSSION

A konus telescope crown serves as a retainer for partial dentures. However, it is difficult to adjust the retentive force. The retentive force of konus telescope crowns is achieved by wedge effect. In other words, when an outer crown is seated on an inner crown and a load is applied to the occlusal surface, the side surface of outer crown is slightly deformed by wedge effect, thereby achieving the retentive force. It should be highlighted that this retentive mechanism is different from that of conventional cylinder-type telescope crowns. Therefore, in the absence of any minute gap at the occlusal part between inner crown and outer crown, the slight deformation of the outer crown would not occur, which means that the retentive force would not be achieved[6].

Typically, the konus telescope crown is made by lost wax method. During investing outer crown's wax pattern, the dental technician must adroitly

adjust the water-powder ratio of dental investment and control the expansion of the casting mold to obtain an appropriate gap between the inner crown and outer crown. Therefore, there is heavy reliance and extremely high demand on the ability, experience, and sensitivity of the dental technician.

In recent years, however, the CAD/CAM system has gained much attention in clinical dentistry. It has even emerged as the new metal processing method substitute for the conventional lost wax method. However, when manufacturing crowns using a CAD/CAM system, an expensive precious metal alloy is unsuitable because the quantity of ingot required for cutting far exceeds that required for the completed crown. Titanium, on the other hand, is considered to be a suitable material for the CAD/CAM system because of its many relevant advantages: it is inexpensive and it has excellent biocompatibility and corrosion resistance. Against this background, we conceived the notion of making pure titanium konus telescope crowns using a CAD/CAM system.

The retentive force of a konus crown is influenced by many factors, such as the width and height of inner crown, axial taper angle, adaptability of outer crown, and gap width in the occlusal region between inner and outer crowns[6]. On the influence of these factors, Kiyama et al. have established that changing the form of konus inner crown would lead to differences in retentive force[7,8]. In this experiment, we leveraged the merits of the CAD/CAM system to investigate the differences in retentive force by changing the gap width in the occlusal region between inner and outer crowns. At this juncture, it should be mentioned that if the konus crown were fabricated by conventional casting technique, it would be difficult to maintain a constant gap width.

When placing a konus telescope partial denture in the mouth, retentive force is achieved by applying a load. If the applied load increases, expanding deformation of the outer crown will also occur, thereby leading to increase in the retentive force of the konus telescope crown. For denture-wearing patients, a daily activity to be addressed is the amount of pressure exerted on the denture when chewing food. A number of researches have been carried out on occlusal pressure during mastication, but the values differed among the studies[9-12]. Besides, occlusal force during mastication varies according to the property of food chewed. Morikawa reported that the average occlusal force during mastication was 12.2 kgf in a dentulous person[11]. On the other hand, Watanabe reported that the occlusal force during mastication was $15.0-38.0$ N in the second premolar region in a complete denture wearer[12]. In view of these results in previous studies, the applied load to outer crown in this study was predetermined to be 50 N and 100 N.

Regardless of specimen height, it was found that as the gap width at occlusal part between inner crown and outer crown increased, the retentive force of konus crown also increased. Moreover, as the applied load to outer crown increased, so did the retentive force of konus crown. On a further note, the retentive force of specimen of 6 mm height was higher than that of 4 mm height. In a former research by Kiyama et al., it was reported that as the axial angle decreased and the height of inner crown increased, the retentive force increased[7,8]. Similarly in this study, an increase in the height of inner crown resulted in an increase in retentive force.

Appropriate retentive force of konus crown lies within the range of 5 to 10 N per abutment piece[6]. In this experiment, under the conditions of 4 mm height and 50 N load — and regardless of gap width at occlusal part, the retentive force values yielded were well within this range. As for specimen of 6 mm height, conditions of 50 N load and 0 μm gap width rendered a retentive force value within this range. It was suggested that the processing accuracy of the CAD/CAM system enabled the required retentive force to be achieved, despite the gap being set to 0 μm.

On the processing accuracy of CAD/CAM system, a previous experiment showed that this new technique produced titanium crowns with fine marginal form and high working accuracy, where accuracy was in the order of tens of micrometers[4]. Therefore, even if the gap in the occlusal area between inner crown and outer crown was set to 0 μm on the computer, a gap was actually produced in this area.

In this experiment, only the surface of inner crown die was polished. In our previous experiment, upon polishing a cast pure titanium plate for 40 seconds with a centrifugal shooting-type polishing machine, the maximum grinding depth was found to be 10 μm[13]. For the surface of inner crown die in this experiment, the amount of grinding was estimated to be the same. Nevertheless, despite the polishing, a gap was observed in the occlusal area between inner crown and outer crown. Consequently, the processing error of the CAD/CAM system was assumed to be more than 10 μm. On the other hand, the inside of outer crown was not polished. Therefore, it was suggested that even minute surface unevenness could affect the adaptation of the outer crown. Further, based on the cross-sectional images of the specimens, it could be said that a taller inner crown die affected the adaptation of outer crown more adversely than a short one.

As for the effect of gap width on retentive force, it was found that for both specimens of 4 mm height and 6 mm height, there were significant differences in retentive force between 0 μm gap and 50 μm gap.

However, no significant differences were observed between 50 μm gap and 100 μm gap.

As mentioned above, the retentive force of konus crown was achieved by slight deformation of the outer crown based on wedge effect. To deform the outer crown, it was necessary for a gap to exist between the inner crown and outer crown. If the reverse side in occlusal area of outer crown were in contact with the occlusal surface of inner crown, then no retentive force would be exhibited. In other words, it was suggested that if the gap was 0 μm, the reverse side of outer crown would already be in contact with the occlusal surface of inner crown, which meant that retentive force would not increase even if more load were applied. In sharp contrast, when the gap was more than 50 μm, the deformation amount of the outer crown would remain the same when the same load was applied. This helped to explain why there were no significant differences in retentive force between 50 μm gap and 100 μm gap, because the retentive force remained approximately the same under the same load.

CONCLUSIONS

Upon measuring the retentive force of konus telescope crowns fabricated using a CAD/CAM system (Dental Cadim) and pure titanium block, the following conclusions were drawn:

1. When the height of inner crown die was high and the applied load was increased, the retentive force of konus telescope crown also became high.
2. As the gap width at the occlusal part between the inner crown die and outer crown increased, the retentive force of konus telescope crown also increased.
3. When the height of inner crown die was 4 mm, appropriate retentive force for konus telescope crown was obtained with 50 N load, regardless of gap width at the occlusal part between the die and outer crown. When the height of inner crown die was 6 mm, appropriate retentive force for konus telescope crown was obtained with 50 N load when the gap was 0 μm.

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