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EFFECTS OF THREE-DIMENSIONAL-PRINTED ZIRCONIA ALL-CERAMIC CROWNS ON PERIODONTAL HEALTH AND AESTHETICS OF PATIENTS RECEIVING ANTERIOR TOOTH AESTHETIC RESTORATION

TRIDIMENZIONALNO TISKANJE CIRKONIJEVEGA OKSIDA NA KERAMIČNE ZOBNE PREVLEKE IN NJEGOV VPLIV NA ZDRAVJE OBZOBNIH TKIV TER PACIENTOVO ZOBNO ESTETIKO PO PREDHODNI ESTETSKI OBNOVI ZOBOVJA

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The aim of this study was to evaluate the effects of three-dimensional (3D)-printed zirconia all-ceramic crowns on the periodontal tissues and aesthetics of patients receiving anterior tooth aesthetic restoration. A total of 85 patients with anterior tooth defects treated from January 2018 to October 2019 were selected. We studied zirconia all-ceramic crowns made by computer-aided design and computer-aided manufacturing (CAD/CAM) (control group) and 3D printing (observation group). The short-term restoration effects, periodontal health indices, functional recovery, long-term clinical efficacy and aesthetic effects were compared. The gingival marginal fitness of the observation group was better than that of the control group, but the control group had better tooth color matching ($P < 0.05$). One year after the restoration, the bleeding index, probing depth, attachment loss, gingival index and plaque index all declined in the two groups, particularly in the observation group. Both the masticatory and language functions were improved in the two groups, especially in the observation group ($P < 0.05$). Both 3D-printed and CAD/CAM zirconia all-ceramic crowns have better cosmetic restoration effects on the anterior teeth. However, 3D-printed zirconia all-ceramic crowns have better gingival marginal fitness, which can benefit the periodontal tissue recovery, relieve gingival inflammation, and improve masticatory and language functions.

Keywords: three-dimensional-printed zirconia, all-ceramic crown, anterior-tooth aesthetic restoration, periodontal health, aesthetics

Namen študije je bil ovrednotenje vplivov popolnega tridimenzionalnega tiska cirkonijevega oksida na keramične prevleke na parodontalno tkivo in estetiko pacienta po predhodni zobozdravniški obnovi zob. Za študijo so izbrali 85 pacientov, katerim so pred tem popravljali poškodbe na zobeh med januarjem leta 2018 in oktobrom leta 2019. Izbrali so prevleke na osnovi cirkonijevega oksida. Izdelali so jih s pomočjo postopka računalniškega oblikovanja in izdelave (CAD/CAM; kontrolna skupina) in postopka izdelave s pomočjo tridimenzionalnega tiskanja (opazovana skupina). Med seboj so nato primerjali kratkotrajne učinke obeh vrst obnove, indekse parodontalnega zdravja ter funkcionalne popravke, dolgotrajno klinično učinkovitost in estetiko. Marginalni fitnes oziroma zdravje dlesni opazovane skupine je bilo boljše od kontrolne skupine toda kontrolna skupina je imela boljše ujemanje barve zob ($P < 0,05$). Eno leto po obnovi so se vrednostni kazalci pri obeh skupinah zmanjšali (indeks krvavenja, globina, izguba pritrditve, dlesenski indeks in indeks pritrditve), še posebej je bilo to izrazito pri opazovani skupini. Funkciji žvečenja in govora sta se izboljšali pri obeh skupinah, še posebej pri opazovani skupini ($P < 0,05$). Obe izvedbi (tridimenzionalnotiskane in s CAD/CAM izdelane prevleke iz cirkonijevega oksida) sta imeli boljši kozmetični vpliv na popravljena zobovja. Dolgoročna pa ima tridimenzionalni tiskan cirkonijev oksid ugodnejši vpliv na zdravje dlesni, kar ima prednost pri obnovi parodontalnega tkiva, zmanjšuje vnetja dlesni, izboljšana sta žvečenje in govorna funkcija.

Ključne besede: tridimenzionalno natiskan cirkonijev oksid, keramične zobne prevleke, predhodna estetska obnova zob, , parodontalno zdravje, estetika

1 INTRODUCTION

Anterior-tooth aesthetic restoration has attracted widespread attention recently.[1] Porcelain-fused-to-metal crowns were widely used restoration materials in the early days, among them the commonly used gold alloy porcelain crowns were typified by few contraindications.[2] However, their shape was not lifelike enough, the tooth was not transparent, the marginal fitness was unsatisfactory, and gingivitis easily occurred.[3] As one of the new materials for restoring tooth defects, zirconia all-ceramic crowns have no metal substrate, but high tissue compatibility, strong corrosion resistance and excellent mechanical properties. Meanwhile, they are not likely to induce gingival inflammation. The color and layer of teeth after restoration are obvious, and the color can remain stable for a long time, so zirconia all-ceramic crowns have been widely applied.[4,5]

The accuracy and fineness of impression directly affect the production of a prosthesis and the accuracy of its placement in the mouth.[6] As a subtractive manufacturing

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method, computer-aided design and computer-aided manufacturing (CAD/CAM) is the main processing method for zirconia all-ceramic crowns. However, the material waste rate is up to 90 % when a fixed prosthesis is prepared with this method. On the contrary, the three-dimensional (3D) printing technique is an additive manufacturing method, which greatly saves materials.[7,8] The marginal fitness of metal crowns made with the 3D printing technique is significantly better than that of cast metal crowns.[9] Until now, the clinical effects of zirconia all-ceramic crowns made with the 3D printing and CAD/CAM on the anterior-tooth aesthetic restoration has remained largely unknown.

Therefore, the aim of this study was to compare the restoration effects of zirconia all-ceramic crowns made with the two impression techniques, and their influences on periodontal tissues and aesthetics. The findings provide valuable evidence for further material design and preparation.

2 EXPERIMENTAL PART

2.1. Baseline clinical data

This study was approved and supported by the medical ethics committee of our hospital. A total of 85 patients with anterior tooth defects treated in our hospital from January 2018 to October 2019 were selected. They selected the zirconia all-ceramic crowns made with CAD/CAM (control group) or 3D printing (observation group) according to their own will.

The inclusion criteria were as follows: 1) Patients aged 18–60 years; 2) those diagnosed with anterior tooth defects and receiving routine single-crown restoration; 3) those who had an intact root canal or had received root-canal therapy; 4) those with no malformation and a normal structure of the maxillofacial region as shown by X-ray, and alveolar resorption or absorption of no more than 1/3; 5) those without systemic chronic diseases affecting the health of periodontal tissues, such as diabetes mellitus; and 6) those who had the basic understanding of the treatment methods and adverse reactions, signed the informed consent and voluntarily received restoration.

The exclusion criteria included: 1) Patients complicated with oral infection and/or systemic infectious diseases; 2) those complicated with periodontal disease, pulp inflammation or chronic inflammation of root apex; 3) those with bad habits such as sleep bruxism and hard biting; 4) those with blood coagulation disorders; 5) those complicated with severe cardiovascular or cerebrovascular diseases; 6) those who had poor compliance in treatment and could not cooperate well; or 7) those with incomplete clinical data, or breastfeeding or pregnant women.

2.2. Methods

All all-ceramic crowns were made by the same technician, and the remaining operations were performed by the same physician. Before treatment, conventional treatment, such as extraction of an affected tooth and periodontal scaling, was conducted for both groups. The color of crowns was selected using the Vitapan 3D-Master shade guide (VITA Zahnfabrik, Germany) under natural light, and the crowns were prepared in line with the requirements of all-ceramic crowns. The points, lines and corners had to be rounded, and the rounded right-angled shoulders had to be at the margin. The margin of the prosthesis was clearly and accurately exposed through single-line gingival retraction. The gingival retraction cord was removed before the final impression, and the gingival sulcus was rinsed and blown dry.

For the control group, a silicone rubber impression was made before tooth extraction. The impression materials were mixed by the same nurse in strict accordance with the instructions. The articulation registration of the prepared silicone rubber impression, superhard gypsum model and silicone rubber was checked correctly, and then the design list was filled out. Then a Lava Plus zirconia ceramic block (3M, St Paul, MN, USA) was cut with a CAD/CAM cutting machine (DWX-50, Roland, Japan) to prepare an all-ceramic crown, and sintered in a sintering furnace, followed by external dyeing by the technician based on the color matching after secondary sintering. For the observation group, the mouth was scanned using CEREC Omnicam (Sirona, Germany) to obtain the optical digital model of the abutment tooth. Then the model was sent to the Artifice Room by the CEREC network. After design, a 3D-printed resin model was made, and the zirconia all-ceramic crown was prepared through stereolithography, followed by thermal debinding and sintering.

The patient wore the unglazed zirconia all-ceramic crown. Its shape, contact point position, adjacent tightness and marginal fitness were checked, and the occlusal gap was adjusted. Then the all-ceramic crown was glazed, ground, kept away from moisture and bonded with resin binder. The occlusal function was checked or adjusted again, and the patient was instructed to clean the interdental space regularly using dental floss, and examined regularly.

2.3. Assessment of short-term restoration effects

One month after restoration, the gingival marginal fitness was assessed based on the following grading system: Grade I (the prosthesis and abutment tooth have good anastomosis, and there is basically no gap. The probe cannot be stuck into or is just slightly stuck into the gap); Grade II (there is a small gap between the prosthesis and abutment tooth where a probe can be inserted); Grade III (there is a large gap between the pros-

thesis and abutment tooth where a probe can be freely inserted).

The integrity of the prosthesis was assessed based on the following grading system: Grade I (without abnormality of the prosthesis); Grade II (small cracks or folds on the prosthesis, not affecting the aesthetics); Grade III (fracture, porcelain collapse or exfoliation of the prosthesis, visible cracks or folds on the prosthesis).

The tooth color matching was assessed based on the following grading system: Grade I (the shape, gloss, color and brightness of the prosthesis are basically the same as those of the adjacent teeth); Grade II (the color and gloss of the prosthesis are slightly different from those of the adjacent teeth, but the shape and brightness basically show no differences, not affecting the aesthetics); Grade III (there are greater differences between the prosthesis and adjacent teeth).

2.4. Evaluation of periodontal health indices

Before restoration and one year after restoration, the periodontal health was detected mainly by probing. Bleeding index (BI): A blunt periodontal probe was gently inserted into the gingival sulcus or periodontal pocket bottom at a 45° angle to the tooth surface, and taken out. The gingival bleeding was observed after 30 s. Healthy gums: 0 point; no bleeding but inflammatory changes in the gingival color after probing: 1 point; punctate gingival bleeding after probing: 2 points; bleeding spreading along the gingival margin after probing: 3 points; bleeding overflowing gingival sulcus after probing: 4 points; spontaneous gingival bleeding: 5 points.

Probing depth (PD): The distance between the gingival margin and the gingival sulcus or periodontal pocket bottom; the buccal and lingual mesial/median/distal gingival papillae of each tooth were checked using the probe parallel to the long axis of the tooth with a force of no more than 209, and the average of six sites was taken.

Attachment loss (AL): In the case of gingival recession, AL = distance from the cemento-enamel junction to the gingival margin + PD; in the case of no gingival recession, AL = distance from the cemento-enamel junction to the gingival margin – PD.

Gingival index (GI): Normal gingival shape and color: 0 point; mild gingival inflammation, mild redness with edema, and no bleeding: 1 point; moderate gingival inflammation, redness or small ulcer formation, and proneness to bleeding: 2 points; severe gingival inflammation, redness and swelling, bleeding and congestion without being touched: 3 points.

Plaque index (PI): The tooth surface was slightly scratched using the probe combined with visual inspection. No plaques: 0 point; plaques found on the surface of prosthesis at the gingival sulcus: 1 point; a moderate number of plaques visible to the naked eye: 2 points; a large number of soft mucinous deposits: 3 points. The examinations were performed by two professional dentists receiving uniform training, under natural light, and the data were recorded and checked by two dental interns receiving uniform training. The same batch of examination instruments passing the standard consistency check (*Kappa* >0.8) was used.

2.5. Assessment of functional recovery

Before restoration and one year after restoration, the masticatory function was evaluated. The patients were instructed to chew a certain amount of food within a certain time, and the masticatory function was detected by weighing. The highest efficiency was 100 %, and a higher efficiency meant a better recovery of the masticatory function. Language function: The patients gave a score to the language function according to their daily conversations. The highest score was 10 points, and a higher score indicated a better recovery of the language function.

2.6. Assessment of long-term therapeutic effects

One year after restoration, the long-term therapeutic effects were evaluated based on the following grading system: Markedly effective: The teeth were arranged neatly, and both masticatory and language functions were recovered. There was no pain, and no aching feeling was caused by a hot/cold stimulus at the crown margin. Effective: The teeth were arranged normally, and the masticatory function was obviously recovered. Discomfort was caused by chewing hard food, and temporary reactions were induced by a hot/cold stimulus at the crown margin. Ineffective: Loosening, fracture and even exfoliation of prosthesis, masticatory dysfunction, and further restoration was needed. Total effective rate = (markedly effective cases + effective cases)/total cases × 100 %.

2.7. Evaluation of aesthetic restoration effects

One year after restoration, the aesthetic restoration effect was evaluated by the patients using self-made questionnaires. Aesthetic: The patient felt comfortable, satisfied with the external shape of the full crown without color difference, and behaved naturally and nicely when talking and smiling. Acceptable: The patient felt fine and satisfied with the external shape of the full crown, but there was small color difference, so the patient was a little cautious when smiling. Not aesthetic: The patient felt uncomfortable. There was light discoloration, loosening or even fracture, and the patient was unwilling to expose teeth when smiling.

2.8. Statistical analysis

The SPSS 16.0 software was used for a statistical analysis. The count data were expressed as (*n*, %), and the chi-square test was employed for comparisons between the two groups. The quantitative data were ex-

pressed as the mean ± standard deviation (x ± s). In the case of comparisons between the two groups at multiple time points, the intergroup difference and the time difference in the measured value at each time point were first explored with repeated measures analysis of variance. If there were differences, the SNK-q test was further used to compare the time differences for each group, and the LSD-t test was utilized to compare the intergroup differences at each time point. The test level was $\alpha = 0.05$, and two-tailed P < 0.05 suggested that the difference was statistically significant.

3 RESULTS

3.1. Baseline data

In the control group, there were 43 patients, including 24 males and 19 females aged 18–59 years, with an average age of (36.58 ± 10.27) years. In the observation group, there were 42 patients, including 21 males and 21 females aged 19–60 years, with an average age of (37.16 ± 10.42) years.

3.2. Short-term restoration effects

There was no significant difference in the integrity of prosthesis between the two groups (P > 0.05). The gingival marginal fitness of the observation group was better than that of the control group, while the tooth color matching of the control group was better (P < 0.05) (**Table 1**).

3.3. Periodontal health indices

Before restoration, there were no significant differences in BI, PD, AL, GI and PI between the two groups (P > 0.05). One year after restoration, BI, PD, AL, GI and PI all declined in the two groups, more significantly in the observation group (P < 0.05) (**Table 2**).

3.4. Functional recovery

Before restoration, the masticatory and language functions showed no significant differences between the two groups (P > 0.05). One year after restoration, both functions were improved in the two groups, especially in the observation group (P < 0.05) (**Table 3**).

3.5. Long-term therapeutic effects

The total effective rates of the control and observation groups were 97.67 % and 100 %, respectively. No significant difference was found in the long-term clinical efficacy between the two groups (P > 0.05) (**Table 4**).

Table 1: Short-term restoration effects

Group	n	Gingival marginal fitness (n, %)			Integrity of prosthesis (n, %)			Tooth color matching (n, %)		
		Grade I	Grade II	Grade III	Grade I	Grade II	Grade III	Grade I	Grade II	Grade III
Control	43	30(69.77)	11(25.58)	2(4.65)	36(83.72)	6(13.95)	1(2.38)	41(95.35)	2(4.65)	0(0.00)
Observation	42	40(95.24)	2(4.76)	0(0.00)	38(90.48)	4(9.52)	0(0.00)	30(71.43)	11(26.19)	1(2.38)
χ^2		9.649			1.443			8.925		
P		0.008			0.486			0.012		

Table 2: Periodontal health indices

Group	n	BI (point, $\bar{\chi}$ ± s)		PD (mm, $\bar{\chi}$ ± s)		AL (mm, $\bar{\chi}$ ± s)		GI (point, $\bar{\chi}$ ± s)		PI (point, $\bar{\chi}$ ± s)	
		Before restoration	1 year after restoration	Before restoration	1 year after restoration	Before restoration	1 year after restoration	Before restoration	1 year after restoration	Before restoration	1 year after restoration
Control	43	3.82 ± 0.57	1.64 ± 0.25*	3.41 ± 0.37	2.38 ± 0.29*	2.53 ± 0.31	1.87 ± 0.21*	1.75 ± 0.23	0.82 ± 0.14*	2.06 ± 0.31	1.48 ± 0.22*
Observation	42	3.86 ± 0.55	0.93 ± 0.16*	3.38 ± 0.36	1.94 ± 0.21*	2.48 ± 0.29	1.33 ± 0.15*	1.73 ± 0.22	0.46 ± 0.07*	2.09 ± 0.32	0.74 ± 0.13*
t		0.329	15.554	0.379	7.996	0.768	13.614	0.410	14.939	0.439	18.823
P		0.743	0.000	0.706	0.000	0.445	0.000	0.683	0.000	0.662	0.000

AL: attachment loss; BI: bleeding index; GI: gingival index; PI: plaque index; PD: probing depth *P < 0.05 *vs.* before restoration

Table 3: Functional recovery

Group	n	Masticatory function (%, $\bar{\chi}$ ± s)		Language function (point, $\bar{\chi}$ ± s)	
		Before restoration	1 year after restoration	Before restoration	1 year after restoration
Control	43	41.58 ± 2.63	83.92 ± 3.86*	6.72 ± 0.81	8.55 ± 0.93*
Observation	42	41.36 ± 2.59	89.78 ± 4.65*	6.69 ± 0.78	9.12 ± 1.04*
t		0.388	6.328	0.174	2.665
P		0.699	0.000	0.862	0.009

*P < 0.05 *vs.* before restoration

Table 4: Long-term therapeutic effects

Group	*n*	Markedly effective (*n*, %)	Effective (*n*, %)	Ineffective (*n*, %)	Total effective rate (*n*, %)
Control	43	35(81.40)	7(16.28)	1(2.33)	42(97.67)
Observation	42	39(92.86)	3(7.14)	0(0.00)	42(100.00)
χ^2		2.805			0.988
P		0.246			0.320

Table 5: Aesthetic effects

Group	*n*	Aesthetic (*n*, %)	Acceptable (*n*, %)	Not aesthetic (*n*, %)
Control	43	32(74.42)	9(20.93)	2(4.65)
Observation	42	34(80.95)	7(16.67)	1(2.38)
χ^2		0.632		
P		0.729		

3.6. Aesthetic effects

The aesthetic effect showed no significant difference between the two groups (P > 0.05) (**Table 5**).

4 DISCUSSION

Zirconia all-ceramic crowns not only exhibit high marginal fitness and biological compatibility, but also a better aesthetic effect than that of porcelain-fused-to-mental crowns.[10] The placement, gingival marginal fitness, qualification rate of occlusal relation and prosthesis appearance of zirconium dioxide all-ceramic crowns made with CEREC intraoral scanning combined with 3D printing are all superior to those of the crowns made with silicone rubber impression.[11] Marcel et al. found that the zirconia all-ceramic crowns made with CAD/CAM and 3D printing had intact structures without obvious defects, and the outer surfaces were smooth without visible sticky powders or cracks.[12] The porcelain white 3D-printed all-ceramic crowns are slightly inferior to the CAD/CAM all-ceramic crowns in the restoration of the tooth color, but the marginal and internal fitnesses of the former are better. The results of this study are consistent with those of the above references. As a commonly used oral impression material, silicone rubber is characterized by stable chemical properties, high fluidity, precision and strength, making it easy to obtain a complete and clear impression. Moreover, it has strong abilities of elastic recovery and detail reproduction. Although the size change in the silicone rubber impression remains stable at 0.5 % within 24 h, the operation may be difficult due to the complicated manufacturing process, or information deviation can be caused due to gingival sulcus bleeding, salivary secretion and infusion of gypsum models. Additionally, the impression and models may suffer from deformation during disinfection, storage and transportation. Moreover, wear and tear are inevitable in the process of gypsum model trimming, thus affecting the restoration effect.[13] On the contrary, a 3D-printed model is easy to measure while avoiding wear and tear, which can ensure the accuracy of data.

Excessive material consumption is the main disadvantage of CAD/CAM machining. The model of cutting head limits the shape of prosthesis, and the cut material cannot be reused, resulting in a great waste. 3D printing allows accurate and efficient restoration while remedying the shortcomings of the CAD/CAM subtractive cutting mode.[14] More importantly, a high-precision prosthesis is more beneficial to periodontal restoration.[15,16] In a study on the performance of 3D-printed individualized zirconia implants in adult Beagle dogs, Zhu et al. found that the bending resistance, compressive strength and elastic modulus of 3D-printed zirconia materials were closer to those of natural bone tissues.[17] There was no cytotoxicity, and the implant could be put in place in the extraction socket without inflammation or exfoliation, firmly bound to the surrounding bone tissues. Likewise, in this study, 3D-printed zirconia all-ceramic crowns were more conducive to the recovery of periodontal tissues and alleviation of gingival inflammation. Zirconia materials have high biological compatibility without the toxicity to soft tissues, and do not lead to complications such as allergy, gingival staining or hemorrhagic necrosis. Besides, the data measured by 3D printing are more accurate and the gingival marginal fitness is better, so the 3D-printed zirconia all-ceramic crowns fit better and have better coordination with the original teeth.

If not treated promptly, dentition defects reduce or eliminate the masticatory function, increase the burden on the gastrointestinal tract, affect the digestive function and weaken the language function of patients. In addition to the masticatory and language functions, the aesthetic restoration effect of a fixed prosthesis has long been the concern of the patients with dentition defects.[18] Almarza et al. reported that compared with casting all-ceramic crowns, zirconia all-ceramic crowns greatly improved the masticatory function and aesthetics of patients after restoration.[19] Beisdes, Della et al. found that the occlusal relationship and aesthetics of the patients with dentition defects were significantly better, and the recovery time of dental function was significantly shorter after 3D-printed zirconia restoration than after conven-

tional dentition restoration.[20] Similarly, in this study, the masticatory and language functions of the observation group were significantly superior to those of the control group. The 3D-printed zirconia all-ceramic crowns exhibit better gingival marginal fitness, compatibility and coordination with the original teeth. Besides, the long-term clinical efficacy and aesthetic effects showed no significant differences between 3D-printed and CAD/CAM zirconia all-ceramic crowns, possibly because the sample size was not large enough, producing biased results. In addition, we found that the 3D-printed zirconia all-ceramic crowns exhibited better gingival marginal fitness, enhancing the comfort of patients, but the recovery of tooth color was slightly inferior. Therefore, there may be no significant differences in the final evaluation results of the aesthetic effect.

5 CONCLUSIONS

In conclusion, both 3D-printed and CAD/CAM zirconia all-ceramic crowns exhibited obvious cosmetic restoration effects on anterior teeth. However, 3D-printed zirconia all-ceramic crowns have better gingival marginal fitness, which can better benefit the periodontal tissue recovery, relieve gingival inflammation, and improve the masticatory and language functions. In the future, we will further increase the sample size and research centers, and improve the evaluation standards, aiming to obtain more accurate and reliable results.

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