Effects of Ultraviolet Treatment and Alendronate Immersion on Osseointegration of Dental Implants and Mucosal Attachment of Dental Implant Abutments

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Purpose: To evaluate the effects of ultraviolet (UV) treatment and alendronate immersion on the osseointegration of dental implants and mucosal attachment of dental implant abutments using a mongrel dog model. Materials and Methods: A total of 48 sandblasted, large-grit, acid-etched (SLA) titanium dental implants and 48 machined surface healing abutments in four male mongrel dogs were prepared. Implants and healing abutments were divided into four groups (n = 12 per group). The control (CON) group did not undergo additional surface treatments. The UV group was treated with UV for 15 minutes, and the alendronate-immersed (AN) group was soaked in 10⁻³ M alendronate for 24 hours. The UV treatment and alendronate soaking (UVAN) group was treated with alendronate, followed by UV irradiation. All implants were placed in the mandible of mongrel dogs, and the animals were sacrificed at 4 and 8 weeks postoperatively. Bone-to-implant contact (BIC), bone density, and connective tissue attachment were measured. Results: In cortical bone, the UV group exhibited significantly higher BIC compared to the CON and AN groups (P < .05). In contrast, the AN and UVAN groups did not have significantly higher BIC. In the trabecular bone, there was no statistical difference between the groups. No significant increase in bone density and connective tissue attachment was shown in any group. Conclusion: UV treatment of SLA surface implants significantly increased osseointegration in cortical bone. The alendronate immersion did not increase osseointegration, and there was no synergic effect with UV treatment. Further, UV treatment and alendronate immersion of machined healing abutments did not significantly increase connective tissue attachment.

Keywords: alendronate, connective tissue attachment, dental implant, dental implant abutment, osseointegration, ultraviolet

Dental implants are a useful treatment option for both fully and partially edentulous patients. For successful treatment with dental implants, initial osseointegration is essential; the rate and quality of the initial osseointegration are intimately related to the surface characteristics of the implants. In particular, the composition, hydrophilicity, and roughness of implant surfaces play important roles in implant-tissue interaction and osseointegration.¹ Therefore, various surface treatment methods have been introduced and developed over the past few years to improve the osseointegration of dental implants.

Sandblasting or acid-etching of the implant surface, or a combination of these, has been developed as a means to enhance the microroughness of dental implants. Of these surface treatment methods, sandblasted, large-grit, acid-etched (SLA) surfaces have been histologically proven to promote bone apposition.² In addition, biomechanical testing has shown that these SLA-treated implants have a high removal torque value.³ Currently, SLA is the most widely used surface treatment method for dental implants, and a retrospective analysis revealed high 10-year survival and success rates of SLA surface–treated implants.⁴

Various methods of improving implant osseointegration by increasing hydrophilicity via an increase in surface energy have also been studied. These are methods such as activation using plasma of argon,⁵ alkali treatment,⁶ and ultraviolet (UV) irradiation.⁷,⁸ When titanium is exposed to air, its characteristics cause its hydrophilicity to slowly disappear due to contact with hydrocarbons.¹⁰ These methods prevent this phenomenon.

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As mentioned, UV irradiation is one way to increase the hydrophilicity of titanium implants. According to a study that applied a push-in test to evaluate the strength of osseointegration, it was shown that UV treatment of acid-etched miniature titanium implants markedly enhanced osseointegration at 2 weeks after implant placement in a rat model. Another study assessed UV treatment–dependent effects on anodized titanium implants in a rabbit model and reported that the bone-to-implant contact (BIC) and amount of bone in the thread area values were significantly higher in the UV-treated group at 4 weeks after implantation, but were not significantly different between the groups at 12 weeks after implantation. An in vivo experiment that assessed the UV treatment–dependent effects on implant osseointegration using a minipig model also reported that there were no statistically significant differences in terms of either the implant stability quotient (ISQ) values at 12 weeks after implantation or BIC measurement at 24 weeks after implantation. Taken together, these findings indicate that UV treatment may not affect the degree of final implant osseointegration but may have a beneficial effect on osseointegration in the initial phase of implantation.

Furthermore, attempts have been made to use bioactive factors, such as bone morphogenetic proteins, fibroblast growth factor–fibronec tin fusion protein, and arginylglycylaspartic acid (RGD)-peptide-modified polymers for implant surface treatments. There have also been attempts to use bisphosphonates for this purpose. Bisphosphonates are bioactive agents that inhibit bone resorption and ectopic calcification, which are mainly used for the treatment of osteoporosis, Paget’s disease, and primary hyperparathyroidism. An earlier study that assessed the use of alendronate in dentistry reported that local application of alendronate on periodontal defects increased the early bone formation rate in a mongrel dog model. A later study on beagle dogs reported that the BIC percentage value was significantly higher in the bisphosphonate-treated titanium implant group than in the non-bisphosphate–treated group at 12 weeks after implantation. In addition, a study that compared four different surface treatments of hydroxyapatite-coated titanium implants using rats reported that an assessment at 3 months after implantation revealed that the bone–implant interface was statistically significantly higher in all three groups treated with bisphosphonate than in the non-bisphosphate–treated group, with the highest value in the zoledronic acid group, followed by the ibandronate group and the pamidronate group. This series of animal studies indicates that alendronate treatment of implant surfaces may effectively enhance osseointegration.

Another important component for successful implants is the soft tissue barrier, which functions as a protective seal between the oral environment and the underlying peri-implant bone. This soft tissue barrier is composed of two layers: epithelial attachment and underlying connective tissue attachment (CTA). These attachments are known to be important for the maintenance of implant osseointegration. Thus, studies on mucosal attachment to the abutment have also been reported. A study that examined mucosal attachment to different abutment materials reported that titanium and ceramic abutments formed epithelial and connective tissue attachments that were 2 mm and 1 to 1.5 mm high, respectively, whereas gold abutments did not form proper attachments and led to bone resorption. Another study reported that the soft tissue remained stable for 2 to 5 months with titanium and zirconium abutments, whereas the barrier epithelium was shifted apically and marginal bone resorption occurred with gold/platinum-alloy abutments, indicating that mucosal attachment can vary depending on the surface properties of the abutment materials.

Similarly, studies have attempted to determine the effects of different surface treatments on mucosal attachment. An in vitro experiment showed that fibronectin coating of smooth (machined), plasma-sprayed, and hydroxyapatite-coated titanium surfaces enhanced gingival fibroblast attachments two- to three-fold, and that laminin coating also enhanced gingival epithelial cell binding. Another study reported that UV-treated titanium surfaces resulted in increased human gingival fibroblast differentiation and adhesion. However, it was difficult to find in vivo studies that investigated the effects of different abutment surface treatments on enhancing mucosal attachment.

This study aimed to examine the effects of UV-alendronate combined treatment of SLA surface–treated implants on osseointegration of implants and mucosal attachment of implant abutments from two different perspectives using a mongrel dog model. The null hypothesis was that there would be no difference in osseointegration and mucosal attachment between the control and UV-treated and/or alendronate-immersed groups at both 4 weeks and 8 weeks after implant placement.

**MATERIALS AND METHODS**

**Experimental Animals, Housing, and Husbandry**

Four male mongrel dogs (aged 24 months, weighing approximately 30 kg) were used in the present study. Experimental animals were housed at room temperature (20°C) with approximately 50% humidity. On the day of surgery, medetomidine (0.1 mg/kg, Tomidin, Provet Veterinary Products) was injected intra-muscularly to sedate each dog. Subsequently, alfaxalone...
(2.2 mg/kg, Alfaxan, Careside) was intravenously injected for general anesthesia. Inhalation anesthesia was maintained with 2% to 2.5% isoflurane, and an electrocardiogram was used for monitoring. For local anesthesia at the surgical site, 2% lidocaine with 1:80,000 epinephrine (2% lidocaine hydrochloride injection, Huons) was injected.

Antibiotic administration was performed according to the following protocol: On the day of surgery, antibiotics (30 mg/kg intramuscular cefazolin sodium, Yuhan) and anti-inflammatory and analgesic medications (0.5 mg/kg IV; Ketorolac, Hana Pharm) were administered for 1 day, and for the following week, antibiotics (13.75 mg/kg; amoxicillin-clavulanate, Boryung Pharmaceutical) and anti-inflammatory and analgesic medication (0.1 mg/kg; meloxicam, Boehringer Ingelheim) were orally administered. Sutures were removed 1 week after surgery. Following tooth extraction, the dogs were maintained on a soft diet until they were sacrificed.

Experimental Procedures

**Surface treatments.** A total of 48 SLA surface–treated dental implants (SuperLine 3.6 × 8.0 mm, Dentium) and 48 machined surface healing abutments (HAB453050E 4.5 × 3.0 mm, Dentium) were prepared. The implants and healing abutments were divided into four groups (n = 12 for each group) as follows:

- **Control (CON) group:** SLA surface implants and machined healing abutments without any additional surface treatments.
- **UV-treated (UV) group:** Implants and healing abutments treated with UV for 15 minutes using a UV light–emitting device (TheraBeam SuperOsseo, Uchio) before implant placement. The UV was delivered as a mixture of spectra via a single UV lamp at wavelengths of 360 and 250 nm.26
- **Alendronate-immersed (AN) group:** Implants and healing abutments soaked in 10−3 M alendronate (Cayman Chemical) for 24 hours.
- **UV treatment and alendronate soaking (UVAN) group:** Implants and healing abutments treated with alendronate, followed by UV irradiation, with each method adhering to the protocol described above.

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**Surgical procedures.** Under general and local anesthesia, eight teeth, from the second premolar to the first molar of the mandible, were extracted. Following tooth extraction and curettage, the sockets were liberally irrigated with saline and sutured with 3-0 synthetic resorbable materials (Vicryl, Ethicon). After a healing period of 3 months, implants were placed under the same surgical conditions as those used for tooth extraction. A researcher (T.H.K.) performed the surgery in blinded to which groups of implants were placed. Another researcher (K.C.O.) prepared four groups of implants with different surface treatments. Implant surgery was performed in the following order: An incision was made on the crest of the ridge to create full-thickness buccal and lingual flaps, and the exposed bone was flattened using a ridge contouring bur. In each adult dog, 6 implants were placed in the mandible on each side, with 12 implants total. Cavities for implant placement were formed with a 2.2-mm guide drill and enlarged with a 2.85-mm final drill.

To prevent overheating during drilling, the site was continuously irrigated with sterile saline. After implant placement, the flaps were sutured with a 3-0 synthetic resorbable material (Vicryl) using the vertical mattress suture technique. The order of the implants placed in each dog is shown in Table 1. In consideration of the difference in the bone quality and the effect of the opposite teeth between the premolar and molar areas, the four groups of implants were evenly distributed to determine the location of the implantation.

The sites where the implants were to be placed were labeled R1, R2, R3, R4, R5, and R6 from the anterior part of the right mandibular molars to the ipsilateral posterior part of the molars, and L1, L2, L3, L4, L5, and L6 from the anterior part of the left mandibular molars to the ipsilateral posterior part of the molars.

At 4 weeks after implant placement, two mongrel dogs (dog no. 2 and dog no. 4) were sacrificed for block bone sectioning, which included the implant sites. The samples were fixed in 10% formalin. The sacrifice was carried out as follows: Zolazepam (5 mg/kg; Zoletil, Virbac) was injected intramuscularly to induce sedation, and the animal was moved from the housing room to the preparation room. A catheter was inserted into the cephalic vein, and alfaxalone (3 mg/kg; Alfaxan, Jurox...
Pty), medetomidine HCl (0.75 mg/kg; Tomidin, Provet), acepromazine maleate (0.6 mg/kg; Sedaject, Samu Median), and tramadol HCl (5 mg/kg; Trodion injection, Aj-upharm) were injected intravenously. Next, the animals were euthanized by inducing cardiac arrest using intravenous injection of potassium chloride (3 g/20 mL; Potassium Chloride-40 injection, Daihan). At 8 weeks after implant placement, the remaining two dogs (dog no. 1 and dog no. 3) were also sacrificed in the same manner for block bone sectioning.

Sample Size
The sample size was determined by referring to a previous study. In this study, the 24 implants were divided into four groups of 6 according to the surface treatment method. According to the previous study, 12 implants per mongrel dog were placed, and therefore two dogs were required. However, in this study, 48 implants and four mongrel dogs were used to analyze the difference between the 4- and 8-week healing periods. This corresponds to a sample size calculation using the degree of freedom.

Histologic Analysis
For histologic analysis, resin blocks were prepared using the following process: First, the specimens were fixed in buffered neutral formalin (Sigma Aldrich) solution for 2 weeks and dehydrated with increasing concentrations of ethanol. For resin infiltration, the dehydrated tissue specimens were placed in a mixture of ethanol and Technovit 7200 resin (Heraeus Kulzer), with an increasing ratio of resin. The infiltrated tissue specimens were embedded in an embedding mold. The specimens were inserted into a UV embedding system (KULZER EXAKT 520, Heraeus Kulzer) and cured for 1 day.

The desired sections of the cured specimens were sectioned using a diamond cutting system (EXAKT 300 CP, EXAKT Advanced Technologies) and were attached to slides using an adhesive press system. The final slides were ground to a thickness of 40 ± 5 μm using an EXAKT grinding system (KULZER EXAKT 400CS, EXAKT Advanced Technologies). Of these, the two most central sections of the implant were selected, and one was stained with hematoxylin and eosin and the other was stained with Goldner’s trichrome to visualize CTA to the healing abutment. Histologic examination was performed using a light microscope (DMR, Leica), and quantitative analysis was performed using computer software (CaseViewer version 2.1, 3DHistTech; ImageJ, National Institutes of Health). Considering previous studies, the osseointegration of implants was evaluated by measuring BIC (%) and bone density (BD %). Mucosal attachment was also evaluated by measuring the CTA (μm). Each definition is as follows:

1. BIC (%): The percentage of bone-to-implant contact length with respect to implant surface length in the cortical bone and trabecular bone areas
2. BD (%): The percentage of the bone area to the total area within a 500-μm-wide zone lateral to the implant between the uppermost thread and bottommost thread
3. CTA (μm): The length from the apical end of the junctional epithelium to the implant-abutment connection, ie, the length of the connective tissue attached to the healing abutment (Fig 1)

The failed implants were planned to be excluded from the analysis. The following conditions were considered implant failures:

1. Horizontal and/or vertical mobility,
2. Uncontrolled progressive bone loss,
3. Uncontrolled exudate, or
4. > 50% bone loss around the implant.

Statistical Analysis
Data were analyzed using statistical software (SPSS Statistics version 25.0, IBM). One-way ANOVA followed by a post hoc least significant difference test was used to identify the effects of UV treatment, alendronate, and different healing periods. The level of significance was set at α = .05.

Ethical Considerations
All experimental procedures were reviewed and approved by the Institutional Animal Care and Use Committee (Yonsei Medical Center, Seoul, Korea; Approval No. 2018-0034). The housing protocol suggested by the Association for Assessment and Accreditation of Laboratory Animal Care International guidelines was followed.

RESULTS

Histology
Low-magnification histologic images showing entire implant parts were examined. Overall, there were no large differences in BD between the CON, UV, AN, and UVAN groups (Fig 2).

Higher-magnification histologic images also did not reveal notable differences in BD between the groups. However, greater bone and implant surface contact was observed in the cortical bone area in the UV and UVAN groups. In contrast, no notable differences were found in the trabecular bone area between the groups (Fig 3).

Histomorphometric Evaluation
Since there were no failed implants, all implants were used for measurement without exclusion. However, due to problems with specimen staining at week 4, one sample from both the UV and UVAN groups was excluded, and a smaller number of samples was used.
for the analysis of CTA. Cortical BIC was significantly increased in the UV treatment group compared to the CON and AN groups (CON [81.55% ± 8.28%] vs UV [89.40% ± 7.41%], \( P = .036 \); UV [89.40% ± 7.41%] vs AN [80.74% ± 11.52%], \( P = .021 \)). In contrast, alendronate-only treatment and UV-alendronate combined treatment did not significantly increase BIC. With respect to the healing period, BIC was significantly higher after 8 weeks of healing compared to 4 weeks of healing in the AN group only (4 weeks [73.43% ± 11.43%] vs 8 weeks [88.05% ± 5.74%], \( P = .019 \)). None of the treatments had any effects on trabecular bone, and no significant difference was found with respect to the healing period (Fig 4).

With respect to BD, none of the treatments showed a significant increase. In the AN group, BD was significantly lower after 8 weeks of healing than after 4 weeks of healing (4 weeks [47.52% ± 7.33%] vs 8 weeks [31.86% ± 12.07%], \( P = .022 \); Fig 5). No significant differences in CTA were found between the groups, and although the values generally increased with a longer healing period, the differences were not statistically significant (Fig 6).

**DISCUSSION**

The null hypothesis of this study was rejected in terms of osseointegration because bone formation improvement in UV-treated groups was observed in vivo. However, there was no difference in mucosal attachment in any group, so the null hypothesis in terms of mucosal attachment was accepted.
UV treatment significantly increased the cortical BIC. In addition, the BIC was significantly higher after a healing period of 8 weeks than after a healing period of 4 weeks. These UV effects were supported by a number of studies, which showed that photochemical modification of the oxide layer on the surface of titanium dental implants—the titanium dioxide surface—via irradiation with UV increases the hydrophilicity and enhances osteogenic differentiation and hard tissue integration.33,34 This is because UV irradiation removes hydrocarbons on the titanium dioxide surface, creating a hydrophilic environment.35 An in vivo experiment also reported the beneficial effects of UV treatment of SLA-surface–treated implants in both cortical and trabecular bone.29

In contrast, none of the treatments had a significant effect on BIC in the trabecular bone area. Despite the lack of effects in trabecular bone, increased BIC in cortical bone by UV treatment has clinical significance because cortical bone plays an important role in the primary stability of implants.36 In particular, this may be more important in short implants or immediate implant placements that are unfavorable to primary stability.37,38

The method in this study of soaking implants in 10⁻³ M alendronate for 24 hours was based on a previous cell-level study.25 However, this treatment did not show a statistically significant effect on the increase in bone formation in terms of BIC and BD. These results were the same as those of some studies that reported that local zoledronate applications were ineffective at enhancing bone adhesion of implants.39,40 On the other hand, several other studies that used different alendronate concentrations and loading methods reported that local alendronate improved implant osseointegration.17,18,41,42 These methods include a calcium phosphate coating method that loads alendronate onto the surfaces,17 a method of creating a crosslinked fibrinogen binding layer,41 and soaking SLA implants in alendronate without pretreatment.42 The bisphosphonate treatment concentrations were also different with 10⁻⁶ M alendronate42 and 10⁻² M alendronate.17 Of these, the method of soaking SLA-surfaced implants in alendronate did not show any significant effects, even though a higher alendronate concentration was used in the present study. This indicates that there is a need for further research to identify adequate methods for alendronate loading on implant surfaces and the most effective alendronate treatment concentration.

Because SLA-surface implants are the current surface treatment of choice, SLA was used as a control group.
in the present study. However, to assess the effects of bisphosphonate, some previous studies used stainless steel screws etched with concentrated hydrogen fluoride with an immobilized fibrinogen layer as a control instead of the SLA surface and compared them to screws with immobilized bisphosphonate on the fibrinogen layer. Therefore, different results may arise depending on the type of implant surface used as a control. In the present study, the SLA surface, which already has sufficient osseointegration capacity, was used as a control, and the implants were placed into bone with sufficient healing, which may explain why no bisphosphonate effects were found. Indeed, one study examined the effects of hydroxyapatite coating and alendronate soaking of titanium-machined and -polished implants on peri-implant defect regeneration when implants were inserted immediately after extraction and found that alendronate treatment was effective in increasing the early bone formation rate. Therefore, the use of bisphosphonates to improve osseointegration of implants would be more valuable in poor bone conditions, such as bone defects, than in ideal conditions.

It is already well-known that bisphosphonate-based drugs such as alendronate may have side effects such as bisphosphonate-related osteonecrosis of the jaw (BRONJ or MRONJ) at systemic administration. Moreover, it has been reported that BRONJ prevalence increases with an increase in the dose of bisphosphonate-based drugs, indicating that if the dose of the drug used is reduced, the side effect can also be reduced. Local injection can limit the use of drugs to a small amount in the area surrounding the implant; furthermore, when alendronate is applied indirectly by soaking the implant in the alendronate, as in this study, a smaller amount of drugs will act locally. Therefore, the side effect will also be very low. Actually, one study reported that local bisphosphonate treatment in a rat model is less likely to induce osteonecrosis of the jaw than systematic treatment. In addition, bisphosphonate treatment duration is an important factor in BRONJ prevalence. The longer the bisphosphonate administration period, the higher the BRONJ prevalence. In the present study, since alendronate was applied locally on a one-time basis, the possibility of complication seems to be very low. However, more research will be needed on the long-term effect of these local application methods.

There was no synergic effect between alendronate and UV in bone formation. These results were different from those of Kim et al, where there was a synergic effect in a rabbit model. However, in the study by Kim et al, the treatment order of alendronate and UV was not specified. In most previous studies examining the effect of UV treatment, UV treatment was conducted chairside before implant placement. In another study, it was reported that the effect of UV treatment could only last a few minutes in ambient air at room temperature. Since alendronate soaking was required for 24 hours, alendronate treatment was first performed in consideration of these previous studies, and then UV treatment was performed immediately before implant placement at the chairside. However, this order may have influenced the results of the group treated by both alendronate and UV. This is because alendronate, an organic compound, can be destroyed by the radical reaction of UV irradiation. Therefore, the effects of alendronate soaking and UV treatment seem incompatible. However, previous studies at the cell level reported that prior UV treatment was helpful in loading more alendronate on the implant surface. Therefore, a follow-up study at the in vivo level is needed.

The present study did not find remarkable UV and/or alendronate treatment effects on mucosal attachment to the healing abutment (machined surface). An in vitro study reported that increasing the hydrophilicity of a UV-treated (wavelength 368 nm, 3.8 W, 24 hours) titanium dioxide–coated surface markedly increased the initial response of human fibroblasts. On the other hand, another study found that UV treatment (wavelength 254 nm, 36 W, 15 minutes) of the titanium surface increased wettability; however, there was no significant increase in human gingival fibroblast attachment. It should be noted that, in that study, UV treatment was administered for 15 minutes, and the authors stated that there is a need to find an adequate UV treatment time for a biologic response. In the present study, 15 minutes of a mixed spectrum of 360- and 250-nm wavelengths was used; therefore, there is a need to identify UV treatment conditions adequate for animal experiments in addition to cellular experiments.

Moreover, the effects of UV and alendronate treatment on bone healing were assessed at 4 weeks and 8 weeks after implantation. The length of these periods was thought to be sufficient for soft tissue healing. Indeed, one study examined the early healing of implants placed in fresh extraction sockets at 1, 2, 4, and 8 weeks after implantation and found complete maturation of epithelium, an absence of inflammation, and the presence of dense connective tissue at 4 and 8 weeks. Therefore, there is a need to examine soft tissue healing earlier.

With respect to the effects of alendronate on mucosal attachment, a previous in vitro study reported that alendronate treatment and UV-alendronate combined treatment of the machined surface both showed no effects on fibroblasts. In fact, the present study, which studied the effects of different surface treatments in mongrel dogs, did not find the increased mucosal attachment of the machined surface abutment with alendronate treatment.
There were several limitations to this study. First, the central section of the implant was selected after sectioning the tissue specimen to measure bone formation and mucosal attachment, but this does not reflect both the 3D bone volume and mucosal attachment around the implants. The healing period was determined to be 4 or 8 weeks, based on previous studies that observed osseointegration of implants using dog models for various purposes. However, as mentioned earlier, a period of 4 to 8 weeks after implant placement may be sufficient time for soft tissue healing in a dog model. This means that the initial soft tissue healing effect according to the surface treatment of the abutment can be masked. Since the number of samples in each group was also small, the results of this study should be interpreted carefully.

CONCLUSIONS

Despite the limitations of the nature of an animal study using a limited number of implants, the following conclusions were drawn. Concerning BIC, UV treatment enhanced the osseointegration of implants. However, these effects were limited to the cortical bone area, and no significant effect was found in the trabecular bone area. Alendronate treatment did not have significant effects on the enhancement of osseointegration, and further research is necessary to investigate effective methods for alendronate loading on implant surfaces. When implants were treated with alendronate, followed by UV irradiation, there was no synergic effect between UV and alendronate for osseointegration. Alendronate and UV treatments did not have significant effects on tissue healing in terms of mucosal attachment. Further research with various UV treatment conditions and healing periods is needed to examine their effects on soft tissue healing.

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