Establishment of experimental models to evaluate the effectiveness of dental trauma splints

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The purpose was to describe a novel simple experimental model of injured teeth for developing dental trauma splints (DTS), and to test various splints by combining use of this model and the Periotest® device. Rubber O-rings and spring washers were used to simulate and modify injured tooth mobility. Splinting effects were assessed among three kinds of DTS, including a composite splint and two wire-composite splints (1: rectangular orthodontic wire 0.533×0.635 mm, 2: cobalt-chromium alloy wire Φ0.9 mm). The Periotest values were measured three times for each tooth before and after splint insertion. The splinting effect was defined as the change in tooth mobility. Splinting effects significantly increased in the order wire-composite splint 1<wire-composite splint 2<composite splint (p<0.05). This model system could evaluate the effects of DTS including the differences among various splint methods, which showed reasonable reproducibility of dental trauma situations depending on severity in clinical usage.

Keywords: Dental trauma splint, Artificial model, Periotest®, Splint effect

INTRODUCTION

Dental trauma splints (DTS) are the cornerstone of therapy for injured teeth. Patients with mobile front teeth may experience problems with food ingestion and aesthetics, and consequently refrain from tooth brushing and often adjust feeding or masticatory habits after suffering dental injuries1). DTS is performed to stabilize injured teeth at their initial position and protect teeth from repeated trauma to support healing2-4). For injured teeth, optimal care consists of keeping the repositioned tooth in its initial position to ensure patient comfort and improve masticatory function5,6). The aim of DTS is to improve the patient’s quality of life during the healing period.

Dentists should consider different types of DTS for injured teeth depending on the nature of trauma, because the DTS degree of rigidity is responsible for the healing of injured teeth2,7-11). In the field of dental trauma, rigidity of DTS is classified into a) flexible: more mobility than a non-injured tooth, b) semi-rigid: same mobility as a non-injured tooth, and c) rigid: less mobility than a non-injured tooth12). In addition, the guidelines for dental trauma management indicated that flexible (non-rigid) splinting assists in healing and ideal splints should allow physiologic tooth mobility and give injured teeth room for slight motion5,6,10).

Previous research on DTS have used various experimental models including commercial4,17-21) or custom-made22-26) artificial model, an animal model27), a human cadaveric model28), and healthy3,29) or injured human models30). Various methods have been used to evaluate DTS including the Periotest device (Medizitechnik Gulden, Modautal, Germany)4,17-21), universal testing machines7,21,23,25,26) and periodontometry27).

As for the characteristics of each model, animal and human models have advantages in terms of clinical relevance, mainly due to the presence of periodontal ligament and tooth enamel, however, their disadvantages include the individual specificity and difficulty to obtain1,3,27-29). On the other hand, commercial artificial models as industrial products are easily obtained and minimal variation exists between products. However, these models require complicated experimental designs to simulate tooth mobility4,17-21).

Among the evaluation systems for DTS effects, the Periotest is a well-established system for evaluating tooth mobility in periodontology30-32), orthodontics33) and dental traumatology1,3,29). The Periotest values (PTVs) correlate with Miller’s classification of tooth mobility30,31,33,34). Moreover, the Periotest is an easier way to evaluate tooth mobility than universal testing machines7,21,23,25,26) and periodontometry27) and is widely used.

A previous study evaluated the DTS effect on a commercial artificial model using Periotest6). In the study, apical parts of artificial teeth were removed and gaps between teeth and sockets were filled with impression materials to simulate a periodontal ligament. The study did not describe how the apical parts of artificial teeth were shortened and PTVs of these teeth before splinting showed a wide range. In other words, mobility or simulation of injured or

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uninjured teeth in the model was not clearly stipulated and, therefore, the method was not an entirely reproducible method. To improve the method, a custom-made artificial model was developed by Berthold et al. consisting of an aluminum base and stainless steel teeth attached with bovine tooth facets. In the model, tooth mobility could be finely adjusted and acid-etching could be performed, however, production of the model was complicated and the model itself differed greatly from human dentition. Therefore, the available experimental models had diverse specifications and there were no unified models.

In clinical situations, dentists encounter opportunities to treat injured teeth with various levels of severity and mobility. Adequate DTS effects can differ depending on the severity of injured teeth. However, there are few simple models simulating dental trauma of varying severity levels.

The purpose of this study was to describe a novel simple experimental model of injured teeth for developing DTS and related materials, and to test various DTS by combining use of this model and the Periotest. Moreover, this study produced two types of simulations with different degrees of injured tooth mobility experimentally to assess the DTS effect according to degree of injured tooth mobility.

MATERIALS AND METHODS

Models
Three artificial models (D18FE-500A-QF, Nissin Dental Products, Kyoto, Japan) with melamine resin teeth (A5A-500, Nissin), rubber O-rings (1A S-2, SAKURA SEAL, Tokyo, Japan) and spring washers (SLW2, MISUMI Group, Tokyo, Japan) were used for this study (Figs. 1a, b). The right central incisor (tooth 11) simulated the injured tooth. The right lateral incisor and left central incisor (teeth 12 and 21) simulated uninjured teeth. To create space between the tooth and socket for simulating injured tooth mobility, lateral incisors of artificial teeth were inserted in central incisor sockets of these models (Fig. 2a). Mesial side of the right cuspid (tooth 13) was thinned by 0.5 mm using a dental hand piece with a carborundum point to maintain the spaces and prevent the influence of interproximal contacts (Fig. 2b).

Simulation of injured teeth (tooth 11)
Two types of simulation differing in degree of tooth mobility according to severity of trauma were produced in this study. One was Level M: moderate (simulated as extrusive or lateral luxation) and the other was Level S: severe (simulated as avulsion or cervical area of root fracture).

1. Level M
A rubber O-ring was placed at the bottom of the socket. An artificial tooth was inserted into the socket and...
locked with a spring washer and an apical fixation screw using an adjustable torque screwdriver (N1.5LTDK, NAKAMURA MFG., Tokyo, Japan) which can control fastening torque. The fastening torque value was 11.0 cN-m.

2. Level S
Unlike Level M, the artificial tooth was not locked with an apical fixation screw. Therefore, there was a need for determining the position of the tooth. The tooth position was determined using silicone putty as a template before splinting. This position was identical to that of the injured tooth in Level M. The tooth did not touch anywhere in the socket when it was fixed by DTS. As the artificial lateral incisor tooth has a smaller root than that of the central incisor, there were gaps between the tooth root and the socket.

**Simulation of uninjured teeth (teeth 12 and 21)**
Rubber O-rings were placed at the bottom of these sockets like the injured tooth. These sockets were filled with softened utility wax (composed mostly of microcrystalline wax) (GC, Tokyo, Japan) which was soaked in hot water (80°C). Immediately after this, artificial teeth were inserted and locked with spring washers and apical fixation screws using an adjustable torque screwdriver. The fastening torque value was 11.0 cN-m. These models were kept for three hours at room temperature (23°C) for the wax to solidify.

The above models are shown as schematic diagrams (Fig. 3).

**Tooth mobility assessment**
Tooth mobility before and after splinting was assessed using the Periotest Classic (Medizitechnik Gulden) (Fig. 4a). This is an electronic system that measures the damping characteristics of the periodontium for evaluating tooth mobility, which can be used in vivo and in vitro and is easy to handle1,3,4,22-34). This device consists of an 8 g tapping rod inside the handpiece. During measurement, the rod taps the tooth surface 16 times in 4 s at a velocity of 0.2 ms⁻¹. The PTVs are calculated from the contact time between the tapping head and the tooth and vary from −8 to 50 in arbitrary units. The model was fixed in a vise (WILTON, La Vergne, TN, USA), when tooth mobility was measured (Fig. 4b). During the measurement of tooth mobility, the handpiece of the Periotest was held at a right angle (handpiece horizontally, tooth axis vertically) at a distance of about 1.5 mm between the tip of the handpiece and the tooth according to the manufacturer’s instructions (Fig. 4c).
The middle of the labial surface of artificial tooth was marked as the measuring point.

Pretreatment of splinting
The area of tooth splint was determined using a thermoplastic sheet and silicone putty as a template. The template was also used to determine tooth position and to avoid materials flowing into proximal areas. Artificial teeth were sandblasted instead of acid-etched. A drop of Clearfil Mega Bond primer (Kuraray, Tokyo, Japan) was mixed with a drop of Clearfil Porcelain Bond activator (Kuraray) and applied in the area of tooth splint. After 30 s, the area was air-dried and Clearfil Mega Bond (Kuraray) was applied in the area. The area was light-cured (Elipar S10, 3M ESPE, St. Paul, MN, USA) for 20 s per tooth.

Splinting
Four kinds of DTS were prepared as follows (Fig. 5).

a) CS1: Composite splint using light-cured resin-based composite (MI Flow II, GC), width 1.5 mm, b) CS2: Composite splint using light-cured resin-based composite (MI Flow II) width 2.5 mm. Resin-based composite was directly injected from a syringe and light cured for 30 s per tooth using an LED light unit. Thickness of CS was 1.5 mm. c) WCS1: Wires (a rectangular orthodontic wire, Blue Elgiloy wire 0.533×0.635 mm, Rocky Mountain Morita, Tokyo, Japan) were cut to the required length as necessary, d) WCS2: Wires (Dental cobalt-chromium alloy wire, SUN-COBALT CLASP WIRE 0.9 mm, DENTSPLY-Sankin, Tokyo, Japan) were cut to the required length as necessary. They were prepared to fit the dental arch using pliers and attached to the tooth surface in designated areas using resin-based composite (MI Flow II). The adhesive area was determined (2×2 mm) and the resin-based composite thickness was 1.5 mm. The width and thickness of the resin-based composite area of WCS and CS were adjusted using a dental hand piece with a carborundum stone and checked using a dial caliper (KORI SEIKI MFG., Tokyo, Japan). All splints were stored in a container for 24 h at 23°C (no humidity control) before measurements.

Evaluation of tooth mobility before and after splinting
As in the study by Berthold, the PTVs were measured three times and averaged for each tooth before (PTVpre) and after (PTVpost) splint insertion. The splint effect was defined as the change in tooth mobility, calculated as the difference between PTVpre and PTVpost ($\Delta$PTV=PTVpre–PTVpost). The PTVpre of the injured tooth in Level S was conveniently determined as a score of 50 which was the max score of the Periotest, because the PTVs of an injured tooth with Level S were not available before splinting. All splints were adapted twice per three models ($n$=6).

Statistical analysis
Data were entered into Microsoft Excel (Microsoft, Redmond, WA, USA). Ekuseru-Toukei 2015 (Social Survey Research Information, Tokyo, Japan) was used for analysis. Nonparametric tests were applied, because the data of PTV were not normally distributed (Kolmogorov-Smirnov test, $p$<0.05). The Wilcoxon test was used to compare PTVpre and PTVpost of every tooth ($p$<0.05). The Mann-Whitney U-test was used to compare PTVpost of injured teeth (11) and PTVpre of uninjured teeth (21) ($p$<0.05). The Steel-Dwass test was used to verify the $\Delta$PTV among all splints and the PTVpre of teeth 12, 11 and 21 among the three commercial artificial models ($p$<0.05). The Steel-Dwass test was applied as a multiple comparison procedure. The $\Delta$PTV among the three artificial models was compared statistically using Kendall’s coefficient of concordance ($w$) to evaluate consistency.

RESULTS
There were no significant differences among the three commercial artificial models in PTVpre of teeth 12 and 21 in each Level. The mean PTVpre for tooth 21 was 1.7±0.4 (mean±SD). There were also no significant differences among the three commercial artificial models in PTVpre of tooth 11 in Level M. Kendall’s $w$ of
ΔPTV among three artificial models was 1.00 ($p<0.05$) in each Level. PTVpre and PTVpost of these teeth in each Level are shown in Table 1. The ΔPTVs are shown in Table 2 and Fig. 6.

### Table 1  Mean (±SD) PTVpre and PTVpost of each tooth for various DTS in Level M (a) and Level S (b)

(a) PTVpre (Level M)

|        | tooth 12 | tooth 11 | tooth 21 |
|--------|----------|----------|----------|
| CS1    | 1.4 (0.3)| 31.2 (1.0)| 1.6 (0.8) |
| WCS1   | 1.4 (0.5)| 31.8 (1.0)| 1.7 (0.4) |
| WCS2   | 1.7 (0.5)| 31.6 (0.8)| 1.8 (0.3) |

PTVpost

|        | tooth 12 | tooth 11 | tooth 21 |
|--------|----------|----------|----------|
| CS1    | 0.6 (0.4)| 0.9 (0.3)| 0.7 (0.4) |
| WCS1   | 1.4 (0.5)| 8.9 (1.8)| 1.4 (0.4) |
| WCS2   | 1.6 (0.3)| 3.8 (0.5)| 1.6 (0.2) |

(b) PTVpre (Level S)

|        | tooth 12 | tooth 11 | tooth 21 |
|--------|----------|----------|----------|
| CS1    | 1.3 (0.4)| 50 (ND)* | 1.7 (0.4) |
| CS2    | 1.5 (0.5)| 50 (ND)* | 1.1 (0.2) |
| WCS1   | 1.5 (0.3)| 50 (ND)* | 1.9 (0.5) |
| WCS2   | 1.4 (0.4)| 50 (ND)* | 1.5 (0.2) |

PTVpost

|        | tooth 12 | tooth 11 | tooth 21 |
|--------|----------|----------|----------|
| CS1    | 1.2 (0.4)| 19.8 (1.4)| 1.8 (0.3) |
| CS2    | 1.4 (0.5)| 12.7 (1.0)| 1.6 (0.4) |
| WCS1   | 1.5 (0.5)| 48.1 (0.8)| 2.1 (0.4) |
| WCS2   | 1.4 (0.3)| 29.6 (0.9)| 1.7 (0.4) |

CS=Composite splint; WCS=wire-composite splint

*: The PTVpre of the injured tooth in Level S was conveniently determined as 50 which was the max score of the Periotest, because the PTVs of an injured tooth with Level S were not available before splinting.

### Table 2  Mean (±SD) ΔPTV of various DTS for injured teeth in Level M (a) and Level S (b)

(a) ΔPTV (Level M)

|        | CS1   | WCS1  | WCS2  |
|--------|-------|-------|-------|
| ΔPTV   | 30.3 (1.0) | 22.9 (1.5) | 27.8 (0.7) |

(b) ΔPTV (Level S)

|        | CS1   | CS2   | WCS1  | WCS2  |
|--------|-------|-------|-------|-------|
| ΔPTV   | 30.2 (1.4) | 37.3 (1.0) | 1.9 (0.8) | 20.5 (0.9) |

CS=Composite splint; WCS=wire-composite splint; PTV=Periotest value

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**Level M**

The mean PTVpre for injured tooth (11) was 31.5±0.9 (mean±SD). The Coefficient of Variation (CoV) of PTVpre for the injured tooth (11) was 3.0%. There were
Fig. 6 ΔPTV of various DTS for injured teeth in Level M (a) and Level S (b).
For each figure, bars (mean±S.D. bar) with different capital letters (A, B, C, D) indicate significant differences (p<0.05) among the kind of DTS.
CS=Composite splint; WCS=wire-composite splint; PTV=Periotest value

statistically significant differences between PTVpre and PTVpost for uninjured teeth (12, 21) in case of only CS1. On the other hand, there were statistically significant differences between PTVpre and PTVpost for injured teeth (11) in all cases. Comparing the DTS rigidity of PTVpost of injured teeth (11) and PTVpre of uninjured teeth (21), PTVpost of injured teeth using all DTS was significantly higher than PTVpre of uninjured teeth. The ΔPTV significantly increased in the order WCS1< WCS2< CS1< CS2.

Level S
There were no statistically significant differences between PTVpre and PTVpost for uninjured teeth (12, 21) in all cases. Comparing the DTS rigidity of PTVpost of injured teeth (11) and PTVpre of uninjured teeth (21), PTVpost of injured teeth using all DTS was significantly higher than PTVpre of uninjured teeth. The ΔPTV significantly increased in the order WCS1< WCS2< CS1< CS2.

DISCUSSION
The purpose of this study was to develop a simple experimental model and reproducible methods for evaluating DTS effects. This study set out to construct trauma models which were easy to handle for researchers and dentists and had small variation among measurement values or models. Commercial artificial models which were standardized and industrial products that could be obtained worldwide were used in this study. It is possible that some discrepancies caused by technical errors of enlarging the model's sockets or removing parts of artificial teeth might occur during the production process because of variation in researcher's skills. Therefore, this study used only artificial teeth supported by with rubber O-rings, utility wax and spring washers and adapted these materials directly to the experimental models. Rubber O-rings (JIS B 2401) and spring washers (JIS B 1251) which were up to the Japanese Industrial Standards (JIS) were used to simulate and modify injured tooth mobility. Utility wax was used for simulating peripheral ligament of uninjured teeth. The utility wax was soft, pliable and tacky at room temperature (congealing point was 64.0°C) and commonly used in clinical procedures in dentistry, for extending impression trays and developing a post-palatal seal. Because temperature-dependent materials were used, all working conditions were under controlled temperature (23°C). All DTS were evaluated twice per three models (n=6). There were no significant differences among the three models, and the ΔPTV among three models showed good agreement. Therefore, these experimental models could reproduce the condition as intended.

According to a previous study on normal PTV in periodontally healthy teeth of individuals aged 20–35 years in vivo, the median PTV in the horizontal dimension was 3.2 (range –0.8–11.2) for the lateral incisors, and 3.6 (range –0.5–13.7) for the central incisors. In the current study, the PTVpre of simulated uninjured teeth (tooth 12 and 21) were 1.5 (±0.4) and 1.7 (±0.4), respectively which was within the range of the in vivo study. Moreover, according to another study on normal PTV of healthy central incisors in males aged 16–22 years in vivo, the mean PTV was 1.8 (±1.1) for tooth 21 which was near the PTV of this study. These findings showed that this experimental model method could successfully simulate uninjured teeth.

Two types of simulations differing in terms of severity were produced. Level M simulated an injured tooth with degree of mobility III (PTVs 31.5±0.9). The fastening torque value was 11.0 cN-m. In a pilot study,
adequate fastening torque value was evaluated to obtain stable PTV of injured teeth at Level M. No one has ever assessed the PTV of teeth right after trauma, mainly because the Periotest should not be applied in the cases of acute trauma according to the manufacturer's instructions. It is conceivable that some injured teeth are too mobile for the Periotest to obtain PTV procedures. Level S represented a severe injured tooth with mobility that was too large to evaluate using the Periotest. In the actual clinical situation, there may be some cases in which dentists apply DTS for injured teeth with severe mobility. But few studies have evaluated the effects of DTS in severe injured teeth with mobility out of the range of PTV.

The Periotest Classic device was used in this study. The PTVs vary from −8 to 50 and correlate with Miller’s classification of tooth mobility: degree of mobility 0, no movement distinguishable, clinically firm teeth, PTV −8 to 9: degree of mobility I, first distinguishable sign of movement, palpable mobility, PTV 10 to 19: degree of mobility II, crown deviates within 1 mm, visible mobility, PTV 20 to 29: degree of mobility III, mobility is easily noticeable and the tooth moves more than 1 mm in any direction or can be rotated in its socket, mobility in response to lip or tongue pressure, PTV 30 to 50: degree of mobility IV, mobility out-of-range of PTV (as in Level S), these teeth can be categorized as flexible splints for injured teeth (Level M).

A difference in adhesive strength between DTS and teeth could affect the effects of DTS. Some researchers tried to reduce the influence of difference in adhesive strength. In the previous studies, there were some experimental models for evaluating DTS effects using human or bovine tooth facets to simulate the clinical experimental models for evaluating DTS effects using strength. In the previous studies, there were some cases in which the differences were observed when using CS1 followed by WCS2 and WCS1. Under CS1, there were no significant differences between PTVpre of uninjured teeth and PTVpost of injured teeth. The results showed that CS1 can be categorized as semi-rigid splints for injured teeth (Level M) according to the requirements for an acceptable splint[15]. Since ΔPTV of CS1 was higher than the maximal required ΔPTV, CS1 might not be acceptable as a splint for injured teeth with a mobility of Level M. PTVpost of injured teeth splinted by WCS1 and WCS2 were significantly higher than the PTVpre of uninjured teeth. Therefore, WCS1 and WCS2 can be categorized as flexible splints for injured teeth (Level M).

On the other hand, in injured teeth with Level S, PTVpost of injured teeth using CS1 and CS2 were in the range of mobility I and WCS1 and WCS2 were in the range of mobility III and II, respectively. The highest DTS effects were observed using CS2 followed by WCS1, WCS2 and WCS1. When injured teeth had a high degree of mobility out-of-range of PTV (as in Level S), these DTS can be categorized as flexible splints, because PTVpost of injured teeth were higher than PTVpre of uninjured teeth with these four DTS[16]. Since the APTV of WCS1 was lower than the minimal required ΔPTV, WCS1 might not be acceptable as a splint for injured teeth with a mobility of Level S.

Results of DTS rigidity in this study were almost similar to those of previous studies in which WCS was a flexible splint[14,24,25,31,32,33,34,35]. On the other hand,
the results of this study were different from previous studies4,20,21,28 that have shown composite splints categorized as rigid splints. In these previous studies, researchers had not defined splint width, thickness or adhesive dimension. The current study aimed to evaluate the influence of the composite splint area on the difference of splint effects. This research defined the width and thickness of composite splints showing that effects of composite splints differed depending on the width of the splint and mobility of injured teeth. Therefore, it may not be appropriate to suggest that composite splints are classified as rigid splints. Composite splints can be useful in immobilizing injured teeth having a high degree of mobility. Adjusting the width or thickness of composite splints may also be necessary depending on the degree of injured tooth mobility from the results of CS1 and CS2 in this study. In future studies, correlation between the width or thickness of composite splints and splint rigidity should be evaluated.

This model system had advantages over the various available models which combined the Periotest with an animal model27, human model28, commercial artificial model19 and custom made artificial model29. In an animal model study using sheep mandible27, it was reported that “the values before splinting differed greatly between jaws tested” (the actual scores were not shown in the publication). Since all front teeth exhibited highly increased mobility, uninjured teeth (adjacent teeth) could not be simulated and evaluated. Also, the study using a human cadaveric model28 showed presplit mobility (Periotest value) ranging from about 2 to about 45 according to the figure (the actual scores were not shown in the publication). On the other hand, the model in the current study successfully simulated uninjured teeth and evaluated the effect of DTS on adjacent teeth, as described earlier. The presplit mobility (PTVpre) of level M ranged from 30.0 to 32.3.

A previous study which evaluated the DTS effect on a commercial artificial model using the Periotest45 did not mention how the simulation of injured or uninjured teeth in the model was performed. Moreover, the PTVs of injured teeth before splinting showed a wide range (CoV=13.7%). Also, in another previous study which evaluated DTS effect on a custom-made artificial model25, researchers made the model with aluminum and stainless steel from scratch. Fabrication of this model was complicated and required many steps including drilling and milling of metal. Because of technical errors of drilling or milling steps would occur. Furthermore, the model was not similar to the human dentition and teeth shape. CoV of the study of injured tooth PTVpre was 4.2%. On the other hand, the current study used commercial artificial teeth replaced with rubber O-rings, utility wax and spring washers and adapted these materials directly to the experimental models in simple steps. CoV of PTVpre injured tooth for Level M in the current study was 3.0%. Therefore, this model system was relatively precise compared to the other models4,22.

This study had some limitations. The inter-observer variances were not evaluated, since only one person evaluated this experiment. Therefore, in order to make it easier for other researchers to reproduce the experimental system, the structure was simplified. All materials were commercially available goods and the method to set the model and measuring procedure were closely defined. To evaluate reliability of this model system and intra-observer variances, agreement of measurement values among three artificial models was evaluated, and was good. Another limitation was that the structure was simplified and clinical relevance was compromised in order to increase reproducibility. For example, the interproximal contact was not given in order to maintain the spaces and prevent the influence of interproximal contacts.

This study evaluated only tooth mobility based on DTS effects and gained limited results. Evaluation of DTS effects require multifaceted approaches. Further studies using this model system are needed in order to evaluate DTS effects using other measurement methods including universal testing machines.

This model system could evaluate the effects of DTS including the differences among various DTS methods. These experimental models were reasonably reproducible of tooth luxation and avulsion often seen in clinical situations. Severity and mobility of injured teeth vary depending on circumstances of accidents. DTS effects should be evaluated in various degrees of severity and mobility. In this study, two levels of injuries were devised. The evaluation methods designed in this study were very simple and easy to apply. This method may be considered useful in evaluating DTS effects.

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