



ORIGINAL ARTICLE

Effects of the type and rigidity of the retainer and the number of abutting teeth on stress distribution of telescopic-retained removable partial dentures

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Abstract *Background/purpose:* Little is known about the force-transmission characteristics and patterns of telescopic-retained removable partial dentures (RPDs) as related to their type and rigidity (rigid and/or resilient) and the number of abutting teeth supporting the telescopic dentures. In this study, we compared the strain around the abutting teeth and edentulous ridges supporting telescopic-retained RPDs with different designs using a strain gauge technique.

Materials and methods: A maxillary model including four abutting teeth (# 14, 13, 23, and 24) was constructed and is referred to as Case 1. In total, four RPD frameworks (two resilient and two rigid) were fabricated for Case 1 with a conventional telescope retainer and attachment-retained telescopic retainer (ARTR) groups. A vertical static load of 280 N was applied, and strain values obtained from the strain gauges were recorded. RPDs were modified according to the following cases—Case 2 included teeth 14, 13, and 23; Case 3 included teeth 14 and 13; and Case 4 included teeth 13 and 23—and measurements were repeated. A randomized block analysis of the variance test was conducted using a general linear model procedure with statistical software. Multiple comparisons between groups were performed using Tukey's honest significant difference test ($\alpha = 0.05$).

Results: RPDs with an ARTR produced more strain distal to the abutting teeth than RPDs with a conventional telescope retainer. Both retainer types with a rigid design produced more strain distal to the abutting teeth than did retainers with a resilient design. RPDs supported by four, three, and two unilateral abutting teeth produced similar strain patterns. RPDs supported by two bilateral abutting teeth produced the highest strain distal to the abutting teeth, but there was no significant difference between the strains produced by RPDs

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supported by either two unilateral or bilateral abutting teeth. The highest strain values were obtained from strain gauges distal to the "terminal" abutting teeth. Directions of the principal strain were in a vertical direction for gauges located distal to the terminal abutting teeth. More strain was produced on the posterior edentulous ridges.

Conclusion: RPDs with an ARTR and both retainer types with a rigid design produced more strain distal to the abutting teeth. Using more than two abutting teeth did not improve the strain patterns of the tested RPDs. More strain was produced on the posterior edentulous ridges.

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Introduction

Achieving long-term success with removable partial dentures (RPDs) requires protection and preservation of the supporting tissues. An optimized distribution of functional forces among the abutments and edentulous ridge is essential and especially difficult to achieve when only a few abutting teeth remain.¹ Selection of an appropriate retainer with regard to the number, alignment, and periodontal status of the remaining teeth in conjunction with esthetic demands is important for a long-term successful restoration.²

Telescopic crowns have proven to be an effective means of retaining RPDs.² They consist of primary coping cemented to an abutting tooth and a precisely fitted secondary crown.^{3–5} They transfer forces along the long axis of the abutting teeth,^{1,2,4} and this transfer creates maximum areas of tension and a minimum amount of compression in the periodontal membrane.⁴

Telescopic crowns are classified into two main groups: rigidly interlocked telescopic crowns and telescopic crowns with built-in resilience. Surface interactions between the primary coping and secondary crown are responsible for retaining rigidly interlocked telescopic crowns when they are engaged.⁵ Telescopic crowns with built-in resilience exhibit no friction during insertion or removal; retention is achieved by using additional attachments or functional molded denture borders, and contrary to other telescopic crown systems, they can be used to retain both tooth-supported and mucosa-supported RPDs.^{1,2} RPDs supported by four or more abutting teeth are considered tooth-supported, whereas RPDs supported by three or fewer abutting teeth are considered mucosa-supported.²

In the Marburg double-crown system, an attachment-retained telescopic crown system has built-in resilience. Retention is achieved by means of an attachment. In this system, the apical one-third of the primary coping is parallel to the secondary crown. The secondary crown is part of the cast framework of the RPD and precisely fits onto the primary coping with no friction or wedging. Primary copings, secondary crowns, and the RPD framework may be cast in one piece using base metal alloys with no soldering or welding. RPDs can be constructed without major or minor connectors due to the rigidity of the framework.^{1,2}

It was previously reported that resilient attachments produce the least force on the abutting teeth compared to

rigid-precision attachments,⁶ and rigid-precision attachments produce more stress than do clasps.⁷ Telescopic retainers are known to produce more strain and transmit more occlusal force to the terminal abutting tooth than do clasps.^{8–10} However, in another study, telescopic distal-extension RPDs provided the most equalized transmission of occlusal forces compared to designs with clasps, precision attachments, or stress breakers.¹¹

Various techniques are applied in biomechanical research for both *in vitro* and *in vivo* investigations. No single technique meets all of the requirements for displaying the extensive physiological interactions involved. The availability of high-capacity computer systems has enabled complex analytical methods in biomechanics such as photogrammetry and finite element analyses (FEAs).¹² However, more-traditional techniques like strain gauge measurements, which are the most accurate instruments used to record surface stresses, were widely used to study the mechanics of prosthetic appliances in previous studies.^{13–15} Differences regarding the quantification of strains between strain gauge measurements and FEAs were found. However, there is mutual agreement and compatibility between these techniques in determining the quality of induced strains under an applied load.¹⁶

In the literature, there are conflicting results about the force-transmission characteristics of telescopic RPDs, and little is known about their force-transmission patterns related with different types, rigidity (rigid and/or resilient), and number of abutting teeth supporting the telescopic dentures.

The aim of this study was to compare the strain around abutting teeth and edentulous ridges supporting telescopic RPDs with different designs using a strain gauge technique.

Materials and methods

An index was obtained from a bilateral distal-extension maxillary cast containing first premolars and canines with an elastomeric impression material (Zetaplus and Oranwash; Zhermack, Badia Polesine, Italy). Two freshly extracted human maxillary canines and first premolars with no distal root deviations were placed in a silicone index and secured with type IV stone (Sherapremium; Shera Werkstoff-Technologie, Lemförde, Germany). The stone cast was attached to a milling machine (Minicruise 430; Silfradent, S. Sofia, Italy), and the teeth were prepared with a preparation

depth of 2 mm, a taper of 3°, and a knife-edge margin design on a common path of insertion. Two pattern resin duplicates were obtained from each prepared tooth (Pattern Resin LS; GC Dental, Tokyo, Japan) and were cast with a Cr–Co–Mo alloy (Biosil F; DeguDent, Hanau/Wolfgang, Germany). Roots of the teeth were coated with a light-viscosity polyvinylsiloxane impression material (Affinis light body; Coltène/Whaledent, Altstätten, Switzerland) to obtain an artificial periodontal membrane with a thickness of 0.3 mm.

Three-element miniature rosette strain gauges (EA-05-031RB-120 Option LE; Vishay Measurements Group, Raleigh, NC, USA) were selected to determine the strain distal to the abutting teeth, and single-element strain gauges (EA-05-125BT-120 Option LE; Vishay Measurements Group) were selected to determine the strain on the anterior and posterior edentulous ridges. The designated positions of the gauges were the buccal alveolus between the canines and first premolars and the distal axial root surfaces of the first premolars for the three-element rosette gauges, and the anterior edentulous ridge along with the left and right posterior edentulous ridges for the single-element gauges (Fig. 1); these were determined with the help of a pilot two-dimensional FEA study. The model consisted of 8648 triangular elements and 2875 nodes, and a vertical static load of 140 N was applied to the first molar tooth region. The FEA modeling was accomplished using Solidworks software (Solidworks 2004; Structural Research & Analysis, Santa Monica, CA, USA), and analyses were carried out using the integrated COSMOS Works 2004 software (COSMOS Works 2004 SP 0.0; Structural Research & Analysis). All materials were assumed to be isotropic, homogeneous, and linearly elastic. Young's moduli and Poisson's ratios of the materials used to construct the FEA model are presented in Table 1.^{17–20} Results of the FEA study are represented as maximum principal-strain values and indicate that similar strain patterns occurred in designated strain-gauge locations (Fig. 2).

Teeth were inserted in the silicone index with the help of temporary crowns, and a clear autopolymerizing resin (Orthocryl; Dentaaurum Group, Ispringen, Germany) was poured into the index; at the same time, strain gauges were embedded at their designated positions, and the index was polymerized in a heat-pressure polymerizing unit (Ivoclar Ivomat IP3; Ivoclar Vivadent AG, Schaan, Liechtenstein) under a pressure of 3 atm at 40 °C for 3 minutes.

Table 1 Young's moduli and Poisson's ratios of materials used to construct the FEA model.

Material	Young's modulus	Poisson's ratio
Cr–Co–Mo alloy	220 GPa ²⁸	0.30 ²⁸
Acrylic resin	1.63 GPa ²⁹	0.37 ²⁹
Brass alloy	117 GPa ³⁰	0.34 ³⁰
Light-viscosity polyvinylsiloxane impression material	1 MPa ³¹	0.30 ³¹
Silicone-based relining material	1 MPa ³¹	0.30 ³¹

After polymerization of the maxillary model, the required electrical connections were hooked up to the strain gauges, and the maxillary model was lined with a silicone-based relining material (Mollosil; Detax, Ettlingen, Germany) with a decreasing thickness from the edentulous ridges to the sutura palatina media region. The completed maxillary model was referred to as Case 1, and the strain gauges were coded as described in Fig. 3.

In total, eight primary copings were fabricated from a brass alloy for the conventional telescope retainer (CTR) group. Four copings had a rigid design with a cervical shoulder as described by Langer,⁵ whereas four had a resilient design as described by Graber.²¹

In total, eight copings were fabricated from Cr–Co–Mo alloy (Biosil F; DeguDent) with resilient and rigid designs for the attachment-retained telescopic retainer (ARTR) group.^{1,2} Primary TC-SNAP-in parts #0101 (Si-tec; Gevelsberg, Germany) were used to fabricate rigid, and #0101L parts (Si-tec) were used to fabricate resilient primary copings as recommended by the manufacturer.

In total, four RPD frameworks were prepared for case 1 (2 resilient and 2 rigid); two of them were cast with a brass alloy for the CTR group, and two were cast with the Cr–Co–Mo alloy (Biosil F; DeguDent) for the Marburg double crown retainer group^{1,2} according to the manufacturers' instructions. Acrylic occlusion rims were fabricated over the frameworks parallel to the horizontal plane with an autopolymerizing acrylic resin (Paladur; Heraeus-Kulzer, Hanau, Germany). A steel plate was attached to both first molar sites to facilitate loading. The maxillary model was attached to the loading apparatus. Strain gauges were

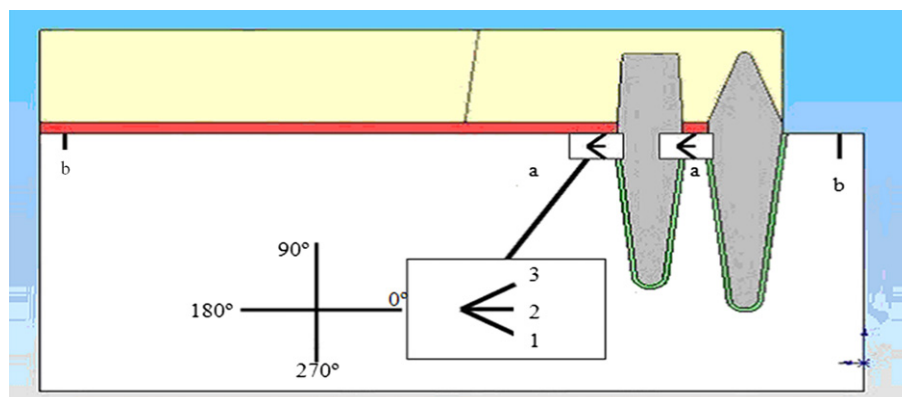


Figure 1 Location of the strain gauges. a = EA-05-031RB-120 Option LE; b = EA-05-125BT-120 Option LE.

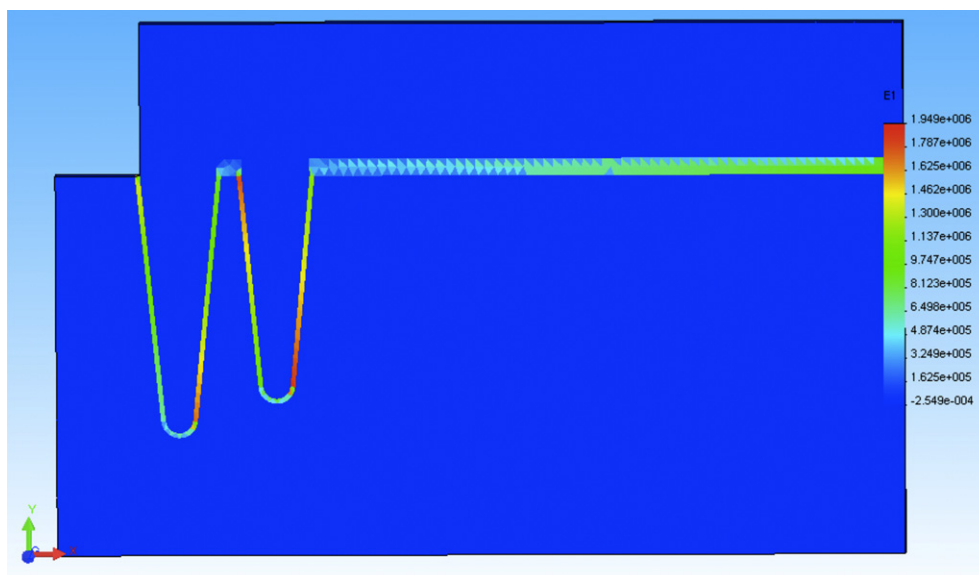


Figure 2 Results of the two-dimensional FEA study represented in maximum principal strain.

connected to a static strain indicator and recorder device (Model P3; Vishay Measurements Group) in a half-bridge configuration with dummy gauges ($3 \times$ EA-05-125BT-120 Option LE; Vishay Measurements Group) installed in a separate acrylic block to provide thermal compensation. A vertical static load of 140 N was applied bilaterally to obtain a total vertical static load of 280 N²² with the help of a loading apparatus, and the strain values were recorded. This procedure was repeated three times, and averages of the three measurements were used for the calculations.

After completing measurements for case 1, the following cases were derived by changing the number or localization of the abutting teeth (Table 2).

As a tooth was removed from the model, the extraction socket was filled with clear autopolymerizing acrylic resin (Orthocryl; Dentauro Group) and covered with a silicone-based liner (Mollosil; Detax); the RPDs were modified for the new configurations. The same loading and measurement protocols were repeated for each case.

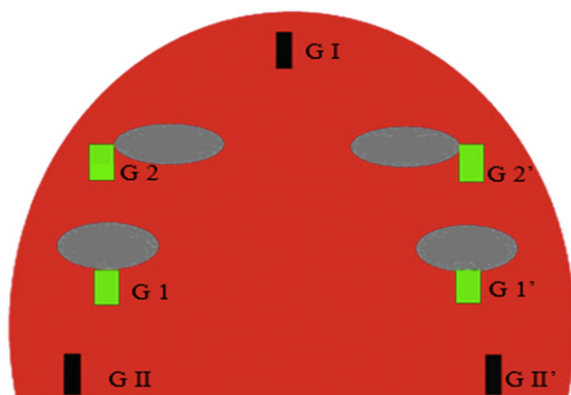


Figure 3 Coding of the strain gauges (G1, G2, G1', G2' distal to the abutment teeth, and GI, GII and GII' on the edentulous ridges).

The strain data obtained from the three-element rosette gauges were transformed to maximum and minimum principal strain values using the formula

$$\varepsilon_{\max, \min} = \frac{\varepsilon_1 + \varepsilon_3}{2} \pm \sqrt{\frac{(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2}{2}}$$

where negative strain values indicate compression strains, and the direction of the principal strain was calculated using the formula $\varphi = 1/2 \tan^{-1} (2\varepsilon_2 - \varepsilon_1 - \varepsilon_3 / \varepsilon_1 - \varepsilon_3)$.^{23,24} Minimum principal strain values were used in the statistical analysis due to their absolute values being more than that of the maximum principal strain. The strain data obtained from single-element gauges were used directly.

A randomized block analysis of variance test was conducted using a general linear model procedure with statistical software (SPSS 11.0.0; SPSS, Chicago, IL, USA). The gauge location factor was considered to be the block factor. Multiple comparisons between groups were made with Tukey's honest significant difference test ($\alpha = 0.05$).

Results

Results of strain values for the abutting teeth indicated that the retainer type, rigidity, case factors, and block were statistically significant ($P < 0.01$), whereas their interactions were not statistically significant ($P > 0.05$).

Table 2 Number and distribution of the abutment teeth for the cases.

Case	Existing abutment teeth
1	14, 13, 23, 24
2	14, 13, 23
3	14, 13
4	13, 23

Table 3 Strain values for the abutment teeth assessed according to the type of the retainer ($\mu\epsilon$).

Retainer type	N	Mean	SD
Conventional telescope	22	-20.72 B	9.39
Marburg double crown	22	-27.99 A	8.29

Capital letters represent differences between the groups (different letters indicate a statistically significant difference). SD = standard deviation.

RPDs with the ARTR produced greater strain distal to the abutting teeth than RPDs with the CTR (Table 3).

Both retainer types with a rigid design produced greater strain distal to the abutting teeth than did the retainers with a resilient design (Table 4).

RPDs supported by four, three, and two unilateral abutting teeth produced similar strain patterns. RPDs supported by two bilateral abutting teeth produced the highest strain distal to the abutting teeth, but there was no significant difference between the strains produced by RPDs supported by either two unilateral or bilateral abutting teeth (Table 5).

The highest strain values were obtained from strain gauges distal to the terminal abutting teeth (Table 6).

Directions of the principal strain were in a vertical direction for gauges located distal to the "terminal" abutting teeth (Table 7).

Results of the strain values for the edentulous ridges indicated that only the block was a significant factor ($P < 0.01$), and strain values obtained from the posterior strain gauges were higher than those of the anterior gauges (Table 8).

Discussion

When applying a vertical force on the distal-extension RPDs, the abutting teeth tend to be displaced very slightly, and the alveolar soft tissues to a greater degree. As a result, stresses transmitted to abutting teeth are more complex in distal-extension RPDs. It was previously reported that the occlusal load distributed to the free-end saddle is closely related to the connecting rigidity of the retainer, and telescopic-retained distal-extension RPDs transfer 80% of the occlusal load to the abutting teeth;⁹ this ratio surprisingly decreases over time.²⁵ Findings of the current study also revealed that the rigid-retainer designs produced greater strain on the abutting teeth than did the resilient designs. When torque around the vertical axis of an abutting tooth was considered, no remarkable differences between

Table 4 Strain values for the abutment teeth assessed according to the rigidity of the retainer ($\mu\epsilon$).

Rigidity of the retainer	N	Mean	SD
Resilient	22	-21.36 B	9.78
Rigid	22	-27.35 A	8.36

Capital letters represent differences between the groups (different letters indicate a statistically significant difference).

Table 5 Strain values for the abutment teeth assessed according to the case factor ($\mu\epsilon$).

Case	N	Mean	SD
1	16	-22.18 B	9.08
2	12	-21.76 B	9.44
3	8	-25.83 AB	9.91
4	8	-31.11 A	7.84

Capital letters represent differences between the groups (different letters indicate a statistically significant difference).

the distal-extension removable RPDs retained by circumferential clasps and telescopic retainers were noted,^{26,27} and the authors explained this phenomenon as the torque around the vertical axis possibly being influenced by factors native to the patient such as properties of the alveolar mucosa, the shape of the alveolar ridge, or the chewing pattern rather than the design of the dentures.²⁷ Furthermore, for the ARTR used in the current study, the mean abutment loss rate was estimated to be 13% after 5 years and 20% after 10 years without a significant difference between the rigid- and resilient-design RPDs with the ARTR.¹

Although there is no scientific evidence considering the force-transmission characteristics of ARTRs, spring-loaded plunger attachments used on splinted abutting teeth can be assumed to have similar force-transmission characteristics with the ARTR used in the current study, which was found to have comparable stress distributions with I-bar-retained RPDs.²⁸ Findings indicating that RPDs with the ARTR cause more strain on the abutting teeth than RPDs with the CTR can be assumed as not critical, as most studies^{7,29} have claimed that the typical "RPI" retainer design produces the least torque on abutting teeth.

In a previous study,³⁰ the mean abutment loss rate was up to 13.7% for telescopic-retained RPDs, but the rate increased to 35.5% for RPDs retained by fewer teeth (40 abutting teeth/24 RPDs). Using more than two abutting teeth for the bilateral distal-extension telescopic-retained RPDs did not improve the survival rate of the RPDs.³¹ This result was supported by the current study's findings.

There was no significant difference between the stresses produced by the denture bases of a rigid extracoronal attachment and the telescopic attachment-retained RPDs on the edentulous ridges in a previous study,⁸ which can explain the similar strain patterns on the edentulous ridges produced by the telescopic-retained RPDs used in the current study.

Table 6 Strain values for the abutment teeth assessed according to the block factor ($\mu\epsilon$).

Block	N	Mean	SD
G1	12	-30.94 A	5.46
G2	16	-19.37 B	7.59
G1'	4	-29.56 A	3.11
G2'	12	-22.67 B	12.03

Capital letters represent differences between the groups (different letters indicate a statistically significant difference).

Table 7 Directions of the principal strain.

		CTR rigid	CTR resilient	ARTR rigid	ARTR resilient
Case 1	G1	262°	263°	263°	263°
	G1'	279°	265°	259°	266°
	G2	304°	356°	277°	3°
	G2'	333°	292°	277°	8°
Case 2	G1	262°	263°	265°	26°4
	G2	298°	23°	278°	4°
	G2'	314°	292°	277°	313°
Case 3	G1	263°	262°	267°	249°
	G2	290°	279°	278°	3°
Case 4	G2	295°	269°	275°	261°
	G2'	357°	294°	309°	318°

Strain gauges are the most accurate instruments for recording surface stresses.¹³ Although there was agreement and compatibility between strain-gauge measurements and the FEA method, strain values obtained from strain gauges were found to be higher than strain values obtained using the FEA method.¹⁶ As no single technique meets all of the requirements for displaying the extensive physiological interactions involved in biomechanical research,¹² designated strain gauge locations of the current study were determined using a pilot two-dimensional FEA study. This approach ensured that similar strain patterns occurred in designated strain gauge locations; thus, the data obtained from the strain gauges could safely be compared with each other. The main limitations of the strain gauges are the limited area over which the strain is measured, which might not be located in the precise region of interest. In addition, in cases where single-element gauges are used instead of rosette strain gauges, the forces acting on the gauges cannot be differentiated. Another limitation of the strain gauge technique is that temperature changes during the operation of the strain gauges require temperature compensation.¹² In recent studies, indirect measurements were made using single-element strain gauges bonded to the alveolus of the terminal abutting teeth¹⁴ or on the edentulous ridge distal to the terminal implants.¹⁵ The strain gauges used in the current study were embedded in the acrylic model instead of being bonded to the surfaces to directly obtain strain values from their intended positions. The efficiency of such a configuration was tested in a pilot study by comparing the strain obtained from single-element strain gauges either bonded to or embedded in autopolymerizing acrylic resin specimens prepared according to the

Table 8 Strain values for the edentulous ridge assessed according to the block factor ($\mu\epsilon$).

Block	N	Mean	SD
GI	16	-10.54 B	5.89
GII	16	-65.96 A	16.91
GII'	16	-54.99 A	15.47

Capital letters represent differences between the groups (different letters indicate a statistically significant difference).

requirements of the American Society for Testing and Materials D 638 type I and subjected to a tension test indicating a correlation coefficient of 0.998.

Conclusions

Within the limitations of this *in vitro* study, the following conclusions were drawn:

1. Retainers with rigid designs produced greater strain distal to the abutting teeth than did retainers with resilient designs.
2. RPDs with the ARTR produced greater strain distal to the abutting teeth than did RPDs with the CTR.
3. Using more than two abutting teeth did not improve the strain patterns of the tested RPDs. RPDs supported by two bilateral abutting teeth produced the highest strain distal to the abutting teeth, but there was no significant difference between the strains produced by the RPDs supported by either two unilateral or bilateral abutting teeth.
4. Directions of the principal strain were in a vertical direction for gauges located distal to the "terminal" abutting teeth.
5. Strain produced on the edentulous ridges was independent of the type of retainer, rigidity of the retainer, and the number and distribution of the abutting teeth. The highest strain values were obtained from posterior strain gauges, indicating a tilting movement positioned vertically.

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