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Editorial

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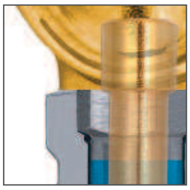
Dental implant system design and its potential impact on the establishment and sustainability of aesthetics

Richard J. Lazzara, DMD, MScD[†]



There is a growing appreciation of the importance of establishing and sustaining the aesthetics of implant restorations. Four important factors for achieving this goal are implant primary stability, the implant surface, implant-abutment junction geometry, and the implant-abutment connection. This article reviews each of these factors as they relate to implant system design and discusses the potential impact these factors can have on long-term aesthetics.

Key Words: aesthetics, implant surface topography, platform switching, PREVAIL®, clamping force, crestal bone preservation

Introduction

It has been 30 years since Per-Ingvar Brånemark first introduced North American dental researchers to his work with endosseous dental implants. During this time, surgical and prosthetic components, as well as the treatment protocols required for implant therapy, have continued to evolve. At the same time, an evolution in the way clinicians think has also occurred. Clinicians whose initial goal was simply to restore function to edentulous patients soon began working toward making the restorations ever more aesthetic. Attention also shifted to expediting and simplifying treatment.

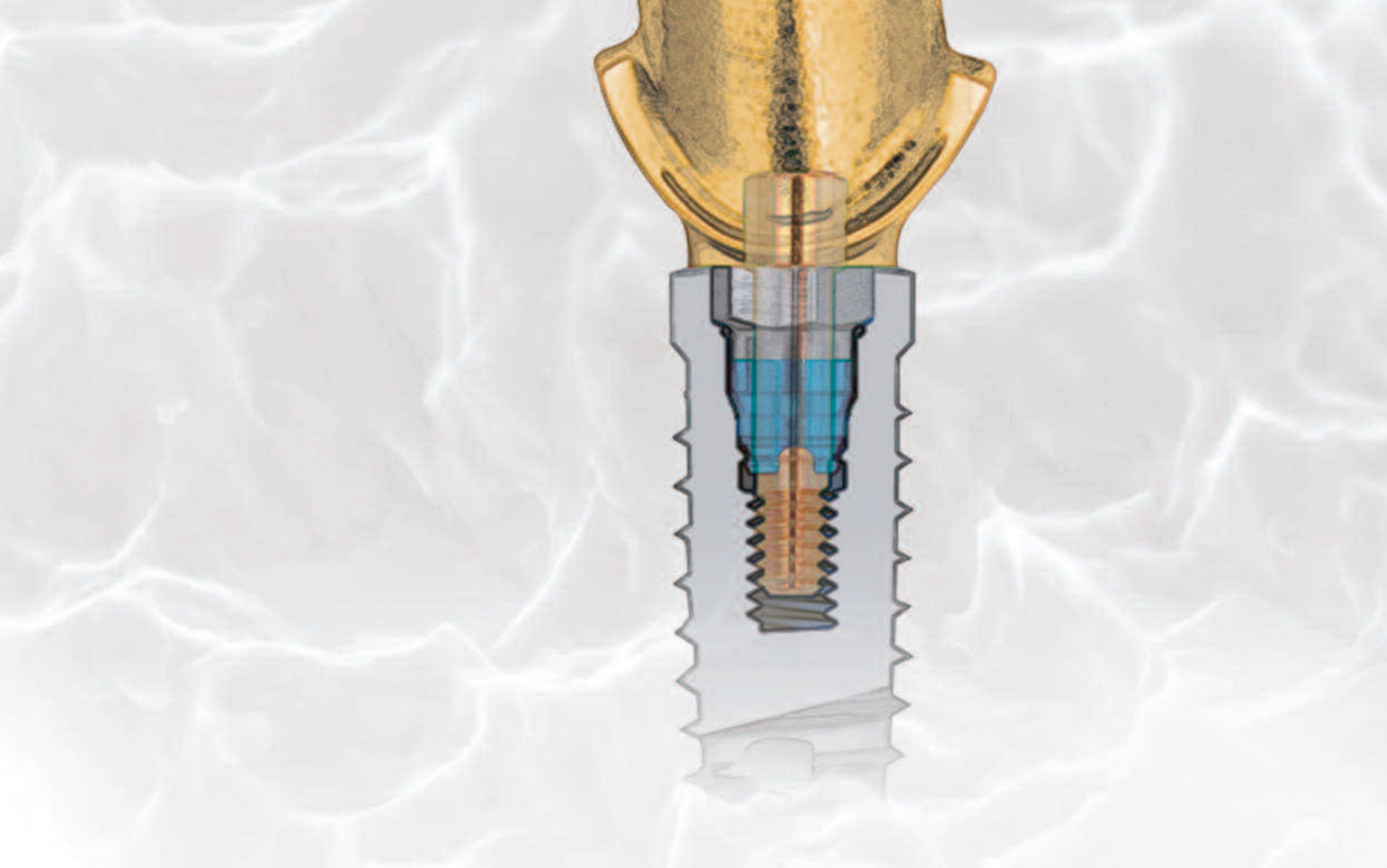
More recently, the realization has been growing that it is not enough to simply place an implant, wait for it to osseointegrate, and then deliver an aesthetic definitive crown. Complex biological processes can sabotage even the most beautiful results over time. Strategies for establishing and sustaining the aesthetics of implant restorations throughout the course of years and even decades have thus assumed paramount importance.

Many factors contribute to the achievement of aesthetic restorations, and that is also true of ensuring that those results are sustainable over time. This article will discuss four important factors in the establishment and sustainability of aesthetic implant restorations. These factors include:

- Implant primary stability
- Implant surface
- Implant-abutment junction (IAJ) geometry
- Implant-abutment connection

Implant Primary Stability

The foundation for aesthetics starts by choosing the correct implant design. When the clinical situation allows, the right implant system can be utilized to begin aesthetically-oriented treatment as early as the day of implant surgery. One can perform a single-stage technique, thereby influencing soft-tissue healing immediately.



A single-stage technique minimizes trauma, helps contour the soft tissues, and potentially preserves them. Another aesthetic option offered by select implant systems is the ability to provisionalize on the day of surgery. This technique provides tissue-sculpting benefits along with the additional reward of an instantaneous aesthetic result.

A critical factor in the success of these early contouring techniques is the primary stability of the implant system. Excessive micromotion during the early healing process has been well documented to impede or prevent osseointegration; it may be the most common cause of implant failure. The primary stability must be sufficient for the implant to resist micromotion until secondary (biologic) stability has been established.[1]

A number of factors enhance the likelihood of achieving primary stability during an implant procedure. For example, one tapered implant system (i.e. BIOMET ***3i***, Palm Beach Gardens, FL) uses depth- and diameter-specific drills to create precise osteotomies that fit the shape (i.e. minor diameter) of the implants being placed. Implants placed so that their entire surface intimately contacts the full length of the osteotomy have been described as having high Initial Bone-to-Implant Contact (IBIC).[2] Such contact enhances primary stability.[3] Furthermore, the implant system selected may incorporate additional macrogeometric design elements to enhance primary stability, including larger thread pitches (i.e., the distance between the threads) and tall, thin threads that penetrate laterally into the bone for secure long-term engagement.

An implant system that routinely enables achievement of high primary stability provides the flexibility needed to treat patient needs. When accelerated treatment is not applicable (e.g. when bone quality is poor), good primary stability minimizes micromotion and reduces the risk of non-integration. When clinical conditions are favorable, primary stability can provide additional benefits, permitting early or immediate provisionalization and/or tissue sculpting to better meet aesthetic demands.

Implant Surface

One of the earliest strategies for enhancing osseointegration was to roughen the implant surface. When compared to the relatively smooth surface of turned titanium, a roughened surface was found to increase bone-to-implant contact and improve the strength of the bone-to-implant interface.[4] In the 1980s, implant manufacturers developed various techniques for roughening implant surfaces, including processes such as titanium plasma spraying and titanium oxide blasting.

While these initial techniques were effective at improving aspects of osseointegration, they often resulted in unforeseen problems. Mucosal and other peri-implant complications were reported for dental implants featuring titanium plasma

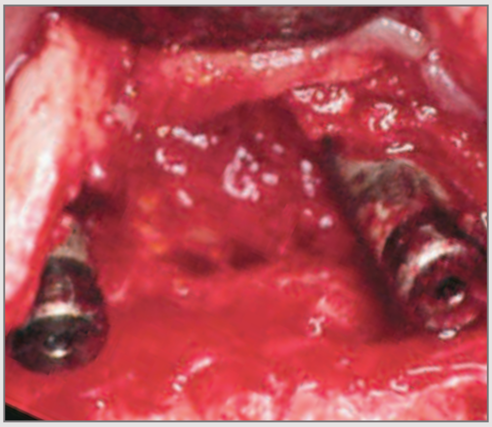


Fig. 1. Evidence of peri-implantitis around titanium plasma sprayed implants.

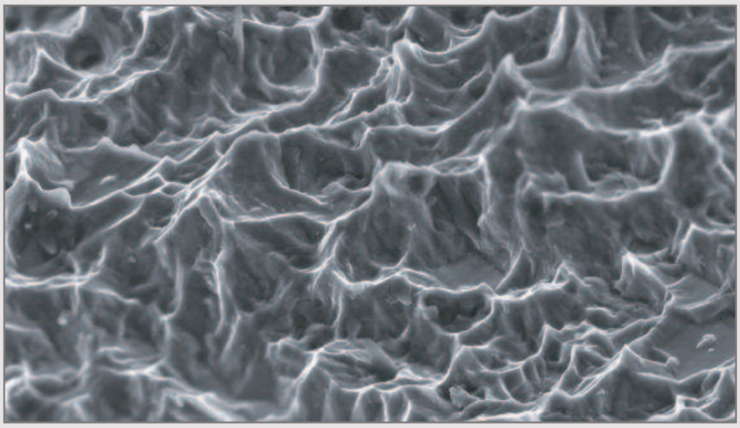


Fig. 2. Dual acid-etched implant surface at 20,000x magnification.

spray (TPS) and other relatively rough surfaces that extended into the coronal aspects (Fig. 1).[5]

In response to these concerns, the industry refined its implant-roughening processes, introducing techniques such as dual acid-etching (DAE) (Fig. 2). The dual acid-etched surface has a two-level topography that includes 1-3 micron pits superimposed on a minimally rough surface (Sa, Absolute Mean Roughness < 1.0 µm).[6] To further reduce the risk of mucosal complications, implants were also made available in hybrid configurations that included the historically proven turned surface on the first few millimeters of the coronal aspects and the roughened surface on the remainder of the implant body.

Subsequent prospective, multicenter clinical studies of dual acid-etched implant designs have reported cumulative survival rates ranging up to 99.3%,[7-10] and meta-analyses of published data showed no decrease in performance under high-risk conditions.[11-13] Human histologic and histomorphometric evaluations have also demonstrated significantly greater bone-to-implant contact, as compared to turned surfaces.[14-16]

In 2010, a prospective five-year multicenter, randomized-controlled study was published that compared hybrid and fully dual acid-etched implant configurations for peri-implantitis incidence.[17] Peri-implantitis is a serious long-term complication, generally characterized by chronic soft-tissue inflammation and irreversible loss of supporting bone.[17] The prevalence of peri-implantitis has been reported to be in excess of 12%.[18] The results of the 2010 study demonstrated that the fully etched surface did not increase the incidence of peri-implantitis as compared to the hybrid implant, while providing additional evidence that the fully etched surface reduced crestal bone loss (0.6mm versus 1.0mm). These results were consistent with the 2009 one-year results of Baldi et al,[19] in which significantly less bone loss was found for fully etched implants (0.6mm) versus hybrid implants (1.5mm).

Both of these findings have significance for clinicians concerned about maintaining patients' aesthetic results over time as it is well known that the maintenance of crestal bone contributes to soft-tissue height and volume, ultimately leading to enhanced aesthetic results.

For dental implants, the surface is critical to achieving and sustaining aesthetic outcomes. To this end, the selection of an implant surface design engineered to enhance osseointegration, preserve crestal bone, and provide a level of protection against the development of peri-implantitis is of paramount importance.

Implant-Abutment Junction Geometry

A third important factor for long-term maintenance of aesthetic restorations is the influence of the implant-abutment junction (IAJ) geometry on the biologic width. The biologic width is the natural seal that develops around any object protruding from the bone and through the soft tissue into the oral environment. It consists of approximately 1.0mm of connective tissue and 1.0mm of epithelium, forming a barrier that protects the bone from bacteria contained in the oral environment (Fig. 3).[20] When implants are placed, connected to transmucosal abutments, and then exposed to the oral environment, the body reacts by re-creating the required

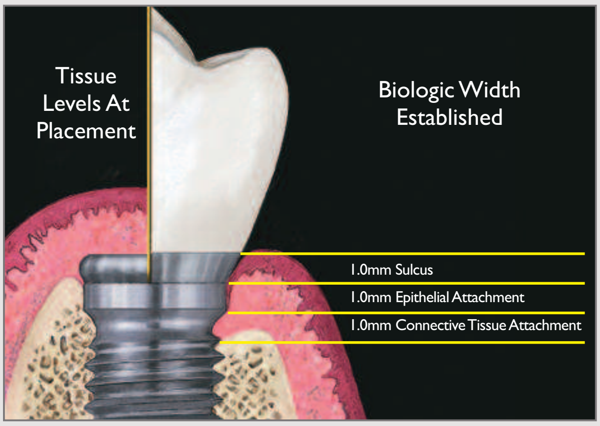


Fig. 3. Schematic showing typical bone remodeling around a standard implant following formation of the biologic width.

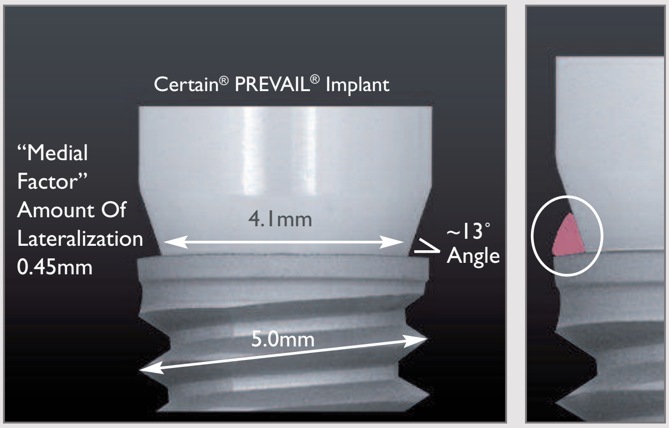


Fig. 4. Schematic of an implant with integrated platform switching. The implant-abutment junction (IAJ) is medialized (shifted inward).

biologic width. If the soft tissues are insufficient, the bone may resorb until an adequate biologic width is re-established.[21] A discovery that occurred in the early 1990s first raised the possibility that implant design could impact biologic width. This discovery occurred when standard 4.0mm diameter abutments were routinely used to restore 5.0mm and 6.0mm diameter implant designs. Radiographic follow-up of these "platform-switched" implants yielded the surprising finding of greater preservation of the crestal bone.[21] This led to the development of implant systems that incorporate platform switching into their design (PREVAIL® Implant, BIOMET ***3i***). Extensive study of the mechanisms at work then followed (Fig. 4).

A recent systematic review and meta-analysis of ten clinical studies including 1,238 implants found significantly less marginal bone loss around platform-switched implants, as compared to platform-matched ones.[22]

There are many hypotheses on how the platform-switch design impacts the biologic width and subsequent bone level. The primary hypothesis is that the platform-switched implant/abutment geometry forms the tissue inward and away from the bone, better sealing off the bone from oral contaminants during normal usage and particularly during component swapping.[23] A related hypothesis is that the biologic width is not strictly a vertical measure but is controlled by the relative surface distance made available by the implant/abutment combination. A platform-switched implant/abutment combination provides additional surface distance through its vertical and horizontal dimensions to establish the required biologic width prior to the bone level being affected.[24] A third hypothesis is that the platform-switching geometry influences the biomechanical stress distributions on the residual bone, leading to preservation.[25] A final hypothesis involves the shift of the IAJ inward, mitigating bone inflammation caused by microbial contamination from a poorly sealed IAJ.[26] Ultimately, the reason why platform switching is effective is most likely the result of one or more of these hypotheses.

Implant designs such as the PREVAIL Implant that incorporate integrated platform switching have been correlated with the preservation of crestal bone.[22,24,25] By eliminating or reducing bone resorption at the top of the implant, the papillae and facial gingival marginal tissue remain supported. Tissue support is critical to the establishment and sustainability of functional and aesthetic outcomes.[27]

Implant-Abutment Connection

A fourth factor that significantly influences immediate and long-term aesthetic outcomes is the implant system connection design. A well-engineered connection will meet user requirements for:

- Ease of use
- Flexibility
- Strength
- Stability
- Fit
- Accuracy

Many of these needs are well known to correlate with aesthetics.

The implant connection should include design features to enhance its ease of use. For example, non-mounted implant

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Item	Description	Endurance Limit N
Ex-Hex Connection Implant	Competitor #1, 3.75 mm diameter	185[29,30]
Internal Connection Implant	Competitor #1, 4.3 mm diameter	283[29,30]
Conical Connection Implant	Competitor #2, 4.1 mm diameter	300[29,30]
XIFNT415	BIOMET *3i* Tapered, 4.0mm Diameter	377[30]
XIIOS4315	BIOMET *3i* PREVAIL, 4.0mm Diameter x 3.4mm Platform	451[30]

Table 1. Results from fatigue testing of implants based on ISO14801 test method (set-up specified as per ISO14801).

designs such as the Certain® Connection (BIOMET *3i*) eliminate steps during surgical placement. Color coding of the connection and associated restorative components provide for ease of selection. In addition to these examples, different implant manufacturers offer unique technologies such as BIOMET *3i*'s BellaTek™ Encode® Impression System that eliminate entire steps (e.g., implant-level impressions) in the restoration process.

The connection design also needs to be flexible, supporting both surgical and restorative needs. Clinicians should never be forced to place implants poorly in osteotomies due to connection rotational limitations (e.g. over-rotating or under-rotating the implant to match a connection point to a buccal landmark). Proper implant design should allow placement with the highest amount of Initial Bone-to-Implant Contact (IBIC) and subsequent primary stability. On the restorative side, the same connection features (e.g. double-hex positions) additionally provide the restoring clinician with maximum aesthetic flexibility. These features allow for simplified restorative procedures, with stock pre-angled or pre-contoured components to restore cases where the implants have been placed in a less than optimal position.

In addition to being easy to use, the implant connection must work synergistically with the implant, abutment, and screw designs to provide the strength required for long-term aesthetic performance. To assess system strength, dental implant manufacturers typically test their systems using the standardized test method described in ISO14801, Dynamic Fatigue Test for Endosseous Dental Implants.[28] The standardization of this test permits the comparison of results provided by various manufacturers. Table I displays the fatigue strength of several industry-leading implant systems.[29,30]

Looking beyond strength, the stability and tightness of the implant/abutment connection may also affect aesthetics. A stable, tight implant/abutment interface minimizes abutment micromotion and reduces the potential for microleakage. Decreasing both of these has been theorized to reduce the inflammatory processes associated with bone or tissue loss.

In a recently presented study,[31] Suttin et al assessed the strength and seal robustness of four commercially available implant systems including Thommen Medical (flat-on-flat connection), Straumann® (conical connection), Astra Tech™ (conical connection), and BIOMET *3i* (flat-on-flat connection). The results of the study demonstrated the potential advantages and disadvantages of the connection designs in terms of microleakage resistance under dynamic load conditions. Figure 5 demonstrates the final failure loads at which each of the samples (n=5 per manufacturer) leaked, fractured, or exhibited a combination of both.

In terms of microleakage, a flat-on-flat connection (Certain® Implant, BIOMET *3i*) had the best performance of all the connections tested. This result runs counter to the assertions of manufacturers of implants with conical connections. The Certain Connection is designed and manufactured with exacting interface tolerances for precise abutment mating and advanced screw technology (e.g. gold coatings, such as the Gold-Tite® Abutment Screw, BIOMET *3i*) to maximize clamping force (Fig. 6.).[32] These factors may help to explain the implant system's high level of performance.

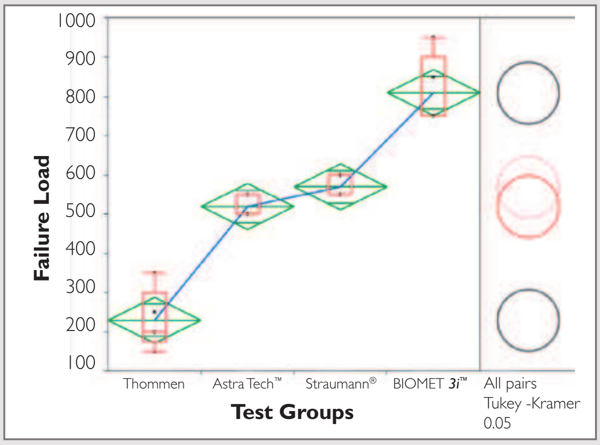

Fig. 5. Ramped cyclic loading.

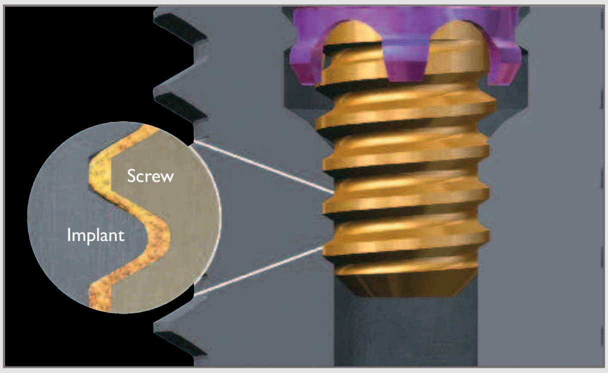

Fig. 6. Gold-Tite® Abutment Screw (BIOMET *3i*). The gold coating acts as a dry lubricant to reduce friction between the screw and the implant threads.

A final important factor in implant connection design is the ability to minimize vertical restorative error. Such error is typically created by the inaccurate transfer of the seating position during the restorative process. The result can be a definitive prosthesis with improper occlusion, contact error, or a non-passive fit.[33,34] The constant seating position of flat-on-flat connections eliminates error sources that are known to plague conical interface connections. Dailey et al[33] and Towse et al[34] identified and quantified sources of conical connection error, demonstrating the potential benefits provided by flat-on-flat connections.

As the dental implant community transitions to digital restorative technologies, new sources of error are emerging. In order for this technology transformation to be successful, it is becoming increasingly critical for all participants in the workflow to minimize their contributions to the overall error. The selection of a connection with a constant seating position could help ensure the success of the digital revolution.

Clinical Relevance

Patients want and increasingly will expect their implant-supported restorations to look as good over time as they did on the day of delivery.

Ensuring that this will be the case requires attention to many factors. Implant design can significantly impact the factors required to establish and sustain aesthetics.

A well-engineered implant system will meet these fundamental clinical requirements providing:

- the primary stability necessary to support early aesthetic provisionalization and/or tissue sculpting.
- a refined surface design to enhance osseointegration, with no increased risk of peri-implantitis as compared to hybrid implants.
- the system strength necessary to provide long-term aesthetic function.
- an implant/abutment geometry and related connection features designed to preserve bone at and around the implant to provide support for the development and maintenance of soft tissue.
- a highly accurate connection well positioned to meet current and future digital restorative needs.

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