ORIGINAL RESEARCH

Comparison of Airway Morphology and Volume in Skeletal Class I and Class II Patients Using Cone-beam Computed Tomography: A Cross-sectional Study

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Abstract

Aim and objective: To compare the airway morphology and volume in skeletal class I and class II patients of ages ranging from 14 to 20 years.

Materials and methods: This retrospective study used cone-beam computed tomography (CBCT) scans of 60 patients in natural head position. Patients were classified into skeletal Class I and Class II based on ANB value and Witt's appraisal. CBCT data was in Digital Imaging and Communications in Medicine (DICOM) format and 3D data and 3D coordinate system were constructed using Dolphin 3D software and airways were analyzed.

Results: Class I skeletal pattern patients had more airway volume (mean = 20733.2 mm^3) than patients with class II skeletal pattern (mean = 19032.2 mm^3), but the results were not statistically significant.

Conclusion: Skeletal class I and class II samples showed "wide" type of airway morphology with skeletal class II patients having more width to depth ratio compared to skeletal class I patients. Airways in class II patients are smaller anteroposteriorly compared to airways of class I patients.

Clinical significance: In this era of airway-centric treatment planning, this study is a stepping stone for understanding the uniqueness and diversity of airway among different individuals and thus plan orthodontic treatment holistically so as to minimize treatment relapse.

Keywords: Airway, Airway volume, Cone-beam computed tomography , Retrospective cone-beam computed tomography study.

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Introduction

The aim of orthodontic diagnosis is to identify dentoalveolar, skeletal, and functional alterations in the maxillofacial complex. Proper diagnosis and treatment planning rely upon a combination of essential diagnostic aids like study models, intra-oral, and extra-oral photographs and radiographs, which traditionally consists of panoramic and cephalometric radiographs.[1] Respiratory function and upper airway morphology are very important for orthodontic diagnosis and treatment planning, as varied breathing function could influence facial growth and morphology.[2] As a significant relationship is found between the pharyngeal airway patency and craniofacial structures in patients with obstructive sleep apnea, an association is expected to exist between upper airway dimensions and the craniofacial pattern. The relation between airway and vertical facial morphology has been well established, but the relation with sagittal morphology is yet to be extensively studied. Hence, it is important to study differences in airway morphology between different skeletal patterns. This will help us understand if there is any relation between airway morphology and skeletal patterns and plan treatment to address airway as well.

Till very recent times, various studies indicated the use of two dimensional radiological methods to determine the area of airway. The disadvantages of this method includes the manual errors in identification of landmarks and also, since airway volume is a three-dimensional entity, it cannot be determined with precision. In recent times, studies on airway volume and its association with various skeletal and facial factors is gaining importance, mostly with the advent of cone-beam computed tomography (CBCT).

Cone-beam computed tomography technology is based on the use of a cone-shaped X-ray beam that is directed through the patient, and the remnant beam is captured on a flat two-dimensional detector. The X-ray source and detector revolve about a patient's head, and a sequence of two-dimensional images is generated. These 2D images are then converted into a 3D image using computer software. CBCT facilitates the visualization and segmentation of airway in 3 dimensions, and thus with its use, the development from length and angles to volume and surface areas are possible. Another important advantage is the reduced radiation dose compared to the conventional computed tomographic (CT) and magnetic resonance imaging (MRI) techniques.

Currently, there is a dearth in the articles pertaining to airway morphology and how it varies in different skeletal patterns. One study had compared the difference in oropharyngeal airway

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morphology of skeletal class I and class III samples and have reported noticeable differences among the two.[3] Although many studies that deals with computing the airway volume among different skeletal pattern existed, studies dealing with morphology of the airway is very limited. The age ranges of the samples in many studies were also very vast. Thus, the present study aims to compare the airway morphology and volume in skeletal class I and class II patients of ages ranging from 14 to 20 years.

Materials and Methods

The study protocol was approved by University (Reference number - UECHT/2016-18/PGDT/02). This retrospective study included CBCT scans of 60 patients which were taken from the patient archives. Hence, sample selection was done retrospectively. The scans that were selected for the study were of those patients whose CBCTs were made using natural head position during the image acquiring procedure with the lips and tongue relaxed. The scans that showed kinetic defects due to involuntary movements like swallowing were omitted.

All the scans in the archives were made using the same machine and using Carestream Software (Carestream 9300) using parameters of 6.3 mA, 90 kvP, and 300 microns resolution with full field of view (FOV) of 17 × 13.5 cm. CBCT scans of healthy patients whose age range was between 14 and 20 years (39 females, 21 males) were selected for this study.

Inclusion criteria applied for the study:

- CBCT of male or female patients with age-group ranging between 14 years and 20 years
- No past history of orthodontic treatment or facial surgery
- CBCT should have been taken with patients teeth in occlusion
- No enlarged tonsil or adenoids

Exclusion criteria applied were:

- CBCT with bite block
- Previous history of orthodontic treatment or surgery
- Congenital anomalies like cleft lip and palate

Patients were categorized into skeletal class I and class II based on ANB value (class I: ANB of 2°–4°, class II: ANB > 4°), Witt's appraisal (where AO was ahead of BO by more than 2 mm was classified under class II skeletal pattern), first molar relationship, and Overjet (class I: Overjet of 2–4 mm, class II–Overjet > 4 mm). After the CBCT samples were collected, the next step was the determination of airway morphology and volume.

The CBCT data were transferred to a computer that stored the data in the Digital Imaging and Communications in Medicine (DICOM) format. A 3D data and 3D coordinate system were constructed and viewed using Dolphin 3D software (Dolphin software, version-11.96, Dolphin Imaging & Management Solutions, Chatsworth, CA).

The measurements were made by DOLPHIN 3D trained author DM (Deaby Mariam). The oropharyngeal airway cross-section was measured along the horizontal plane passing through the midpoint of the bilateral gonion (Fig. 1). Depth and width of the cross-sectional slice was computed by measuring the perpendicular to the narrowest part of the airway linearly (Figs 2 and 3). The shapes of airway for various samples were defined following a cluster analysis. To estimate airway volume using Dolphin 3D, the airway part of interest was defined by identifying the required landmarks and selecting them as depicted in Figure 4.

Boundaries of the Airway

Superior—Superior tip of nasopharyngeal airway

Anterior border—Vertical plane through Posterior Nasal Spine, perpendicular to the sagittal plane.

Posterior border—Posterior wall of the pharynx

Inferior border—Plane tangent to the most medial projection which is in the caudal aspect of the third cervical vertebrae at right angles to the sagittal plane.

First step included restricting the volume of interest from adjacent volumes, and this involved delineating the compartment borders in axial, coronal, and sagittal views. Second, seed points were placed in the target airway. Seed points denote densities that represent the airway. The target airway grow from these seed points. The program automatically filled in and displayed all the airway space within the border chosen. The volume of the airway was displayed in cubic millimeters. The result for each parameter (numbers and percentages) for discrete data was averaged for each parameter and is presented in tables and figures. The Student's *t* test was used to determine whether there was a statistical difference between the groups in the parameters measured. Proportions were compared using Chi-square test of significance and Cluster analysis (group average method) was carried out based on the shape of the oropharyngeal airway after the size parameters of the airway were standardized from 0 to 1.

According to the resulting dendrogram, patients were divided into three variations of the width category according to the ratios between width and depth (Fig. 5). This categorization of airway into type I, II, and III was done by the authors according to the ratios between width and depth. In all the tests, p value less than 0.05 was considered to be statistically significant. The data were analyzed using SPSS package (Version 18.5).

Results

Among 60 samples, 41 were female and 19 were male which made it a percentage distribution of 68.3% females and 31.7% males, respectively. Skeletal class I group had a sample of 30 patients (9 males and 21 females), and skeletal class II group had a sample of 30 patients (10 males and 21 females) which made up a total sample of 60 (Table 1). Age-group of skeletal class I ranged from 15 to 21 years, and for skeletal class II group, age ranged from 14–21 years.

Airway morphology was categorized into the following three types: wide (width > depth), square (width = depth), and long (width < depth). All the 60 samples (30 class I and 30 class II) in this study showed width of the airway being greater than depth

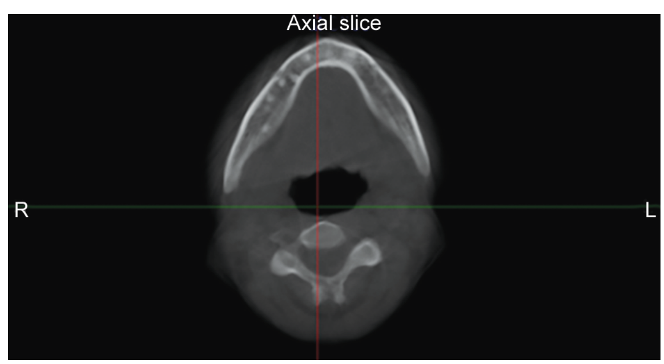


Fig. 1: Cross section of airway taken along the horizontal plane passing through the midpoint of bilateral gonion

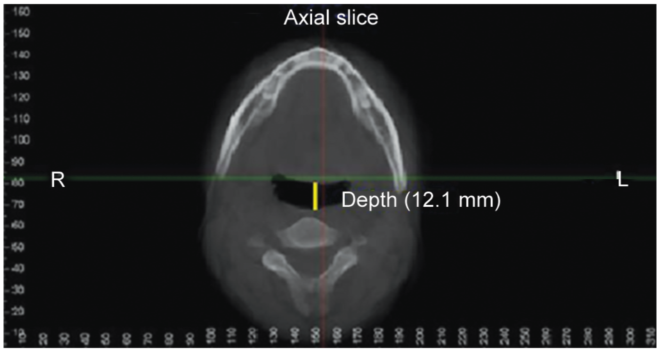


Fig. 2: Evaluation of depth of the airway by drawing a linear line anteroposteriorly in the narrowest part of the airway cross section

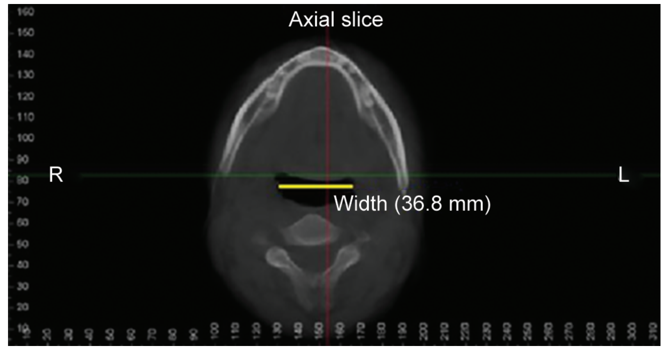


Fig. 3: Evaluation of width of the airway by drawing a linear line transversely in the narrowest part of the airway cross section

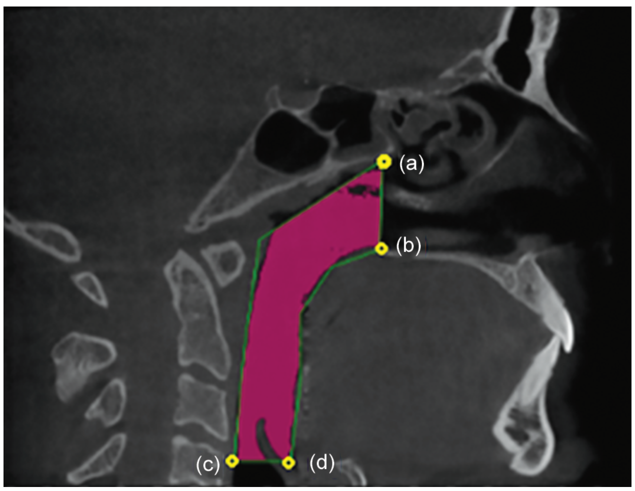


Fig. 4: Landmarks for boundaries of the airway: (a) Superior tip of nasopharyngeal airway; (b) Posterior nasal spine; (c and d) The plane tangent to the most medial projection in the caudal aspect of the third cervical vertebrae at right angles to the sagittal plane and the inferior part of the total airway

which made all the samples fall under the wide category. There was a good correlation between width and depth of airway in all samples (Table 2)

Scatter plot denoting the correlation of width and depth among different samples showed a positive correlation among the two (Fig. 6). A cluster analysis (group average method) was carried out based on the shape of the airway. According to the resulting dendrogram (Fig. 5), patients could be divided into three variations of the wide category according to the ratios between width and depth.

Thus the airway could be categorised under the following category:
Type I: Width:Depth:: 1–1.99:1
Type II: Width:Depth:: 2–2.99:1
Type III: Width:Depth:: 3–3.99:1.

In class I skeletal pattern, type I (63.3%) was more prominently present, whereas in class II it was the least common type (20%). Type II and type III were present in class I samples in 16.7% and 20%, respectively, whereas in class II, type II and type III were present both in 40% (Table 3). The difference between class I and class II were statistically significant with the *p* value of 0.003.

Data showed that patients with class I skeletal pattern has more airway volume (mean = 20733.2 mm^3) than patients with class II skeletal pattern (mean = 19032.2 mm^3), but the results were not statistically significant (Table 4). The airway volume in class I patients ranged from a minimum of 10,659 mm^3 to a maximum of 36,049 mm^3, and the airway volume in class II patients ranged from a minimum of 8,264 mm^3 to maximum of 28,493 mm^3, thus indicating the airway volume in skeletal class I pattern was comparatively more than in skeletal class II pattern.

In the current study, females had more airway volume than males, although the difference was not statistically significant (p value = 0.062 for class I and p value = 0.133 for class II, Table 5)

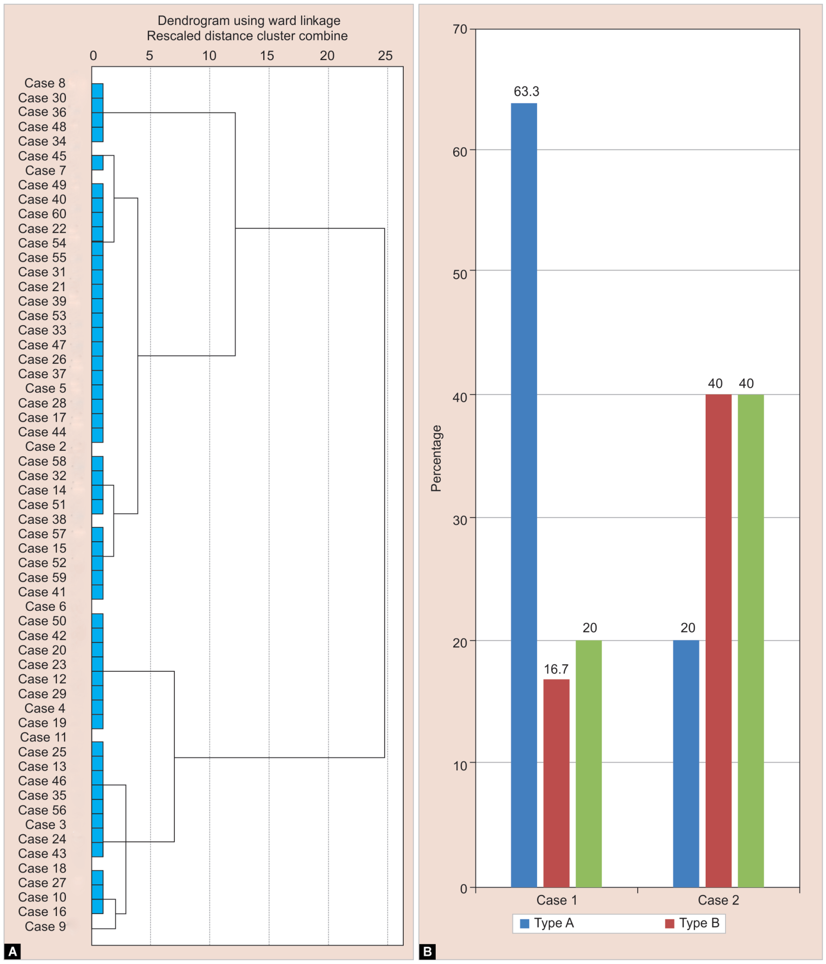
Discussion

According to Aboudara et al., the resistance of airway is related to airway size as well as form.[4] Thus, both parameters are equally important in determining the causes of airway constriction. The purpose of this study was to establish the morphological characteristics of airway among patients with skeletal class I and class II malocclusions and to compare the airway volume among the two skeletal patterns. Three-dimensional CBCT technique was used in this study which had the advantage of producing anatomically true images which were reconstructed in 3D format. This allowed visualization of airway in 3D volumetric images which can be compared using real measurements in 1:1 ratio with less distortion and magnification.

Weissheimer et al. compared the popular CBCT softwares and concluded that Mimics, Dolphin 3D, Osiri X and ITKsnap were similar and more accurate than *in vivo* dental and on-demand for upper airway assessment.[5] In this study, Dolphin 3D (Dolphin software version 11.96, Dolphin imaging solutions, Chatsworth, CA) was used which is a reliable software for airway analysis.

Using ANB alone for identification of skeletal pattern was unreliable as it is subjective to many variables like nasion area morphology, vertical dimension of the face, anterior cranial base inclination and inclination of the jaws. This would have confounded the study as the location of point A and point B will have impact on the angle and not just the sagittal relationship of the jaws. Thus, in addition to ANB values, Witt's appraisal, overjet, and molar relationship were also taken into consideration for identifying the skeletal pattern of the present sample.

In the past studies, the age of the patients varied vastly.[6] Children and adults were considered together in the sample, although it is known that airway volume varies with age. Martin et al. performed a study with individuals aged 16 to 74 years and established that almost all upper airway dimensions decrease as the



Figs 5A and B: (A) Dendrogram showing 3 variations in airway shapes obtained in cluster analysis; (B) Bar diagram denoting the distribution of various types of Wide airway shapes in class I and class II skeletal patterns

Table 1: Percentage distribution of gender and statistical significance of the distribution

	Gender				
	Male	*Female*	*Total*	*χ^2 value*	*p value*
Class I	9	21	30	0.077	0.781
	30.0%	70.0%	100.0%		
Class II	10	20	30		
	33.3%	66.7%	100.0%		
Total	19	41	60		
	31.7%	68.3%	100.0%		

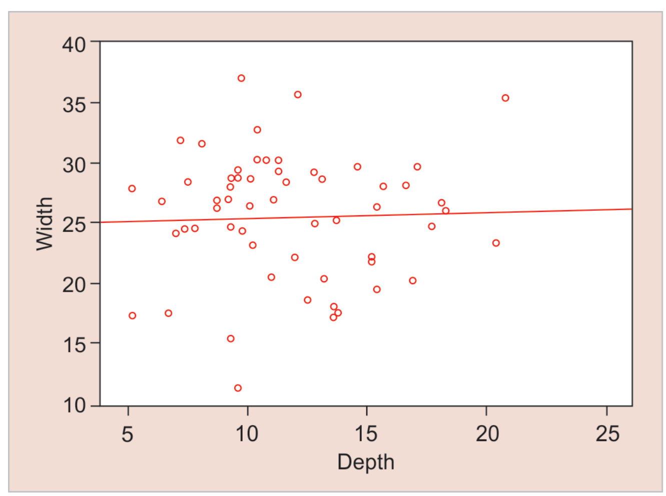


Fig. 6: Scatter plot denoting the correlation of width and depth among different samples

age advances in both men and women.[6] Kollias et al. had performed a long-term follow-up study and had concluded that between 20 years and 50 years of age, there is gradual decrease in airway dimension noted both behind the tongue as well as and posterior to the soft palate.[7] All of these studies suggest that samples for airway studies should be taken from appropriate age to avoid the confounding by different age on airway measurements. In the study by Jeans et al., it was reported that pharyngeal structures continue to grow rapidly till 13 years of age, and a quiescent period was noted between the ages of 14–18 years which meant that the variation of airway size of this age-group was minimal.[8,9] Thus, in this study, age was standardized by taking samples with ages ranging from 14–20 years so as to minimize errors.

The morphology of the airway was established by taking a cross-section of the airway in the transverse plane taken at the gonion point as in the study by Iwasaki et al.[3] By using a fixed landmark like gonion for analysis, uniformity and good reproducibility for subsequent measurements were maintained which reduced the error in the final result. The present study compared the airway morphology of skeletal class I to class II pattern that was not found in the existing literature. The ratio between the width and depth showed noticeable difference among the two skeletal patterns. This observation points light to the fact that in class I patients, the oropharyngeal airway is narrower compared to the airway in class II patients. This may be the fact that in class II, there is retro position of tongue and mandible, and hence the airway is unable to grow in depth and it would have grown in width to maintain the functional volume.

It was observed that there was no statistically significant difference between the airway volume among skeletal class I and class II patterns, which is in accordance with existing literature.[10,11]

Table 2: Correlation between width and depth of cross section of airway among different skeletal patterns

Correlations			
Skeleton pattern			*Width*
Class I	Depth	Correlation	0.180
		p value	0.341
		N	30
Class II	Depth	Correlation	0.095
		p value	0.619
		N	30
Total		Correlation	0.031
		p value	0.816
		N	60

Iveta Indriksone and Guntega Jacobsone had performed a systematic review which included 11 articles narrowed down from 758 studies and observed that 75% of the studies selected did not discover differences in the nasopharyngeal dimensions among craniofacial patterns. Reported findings for the difference in oropharyngeal dimensions were debatable due to presence of many confounding factors like age and vertical growth pattern.[2] El and Palomo and Alves Jr et al. instituted substantial evidence that subjects with retruded mandible are predisposed to smaller airway dimensions that was not supported by findings of Alves and Memon et al.[11–13] In the present study, although the difference in volume is not statistically significant, there was a slight reduction in the mean volume in the class II skeletal pattern samples. This may be due to the fact that if the class II skeletal pattern is caused by the mandible being retrognathic, the overall oropharyngeal airway space will be reduced.

It was observed that although females had marginally more mean airway volume than males, the difference was not statistically significant. This was in accordance with study by Abu Al heija et al. who analyzed a sample of 45 boys and 45 girls of age 14–17 years and found no significant difference in airway volume among the gender.[14] Some authors have reported that there is no statistically significant difference in airway volume between prepubertal boys and girls.[15–17]

Conclusion

- Both skeletal class I and class II samples showed "wide" type of airway morphology with skeletal class II patients having higher width to depth ratio compared to skeletal class I patients. In other words, airways in class II patients are smaller anteroposteriorly compared to airways of class I patients.

Table 3: Percentage distribution of different types of "Wide" airway shapes

	Width/depth ratio					
	Type I	*Type II*	*Type III*	*Total*	χ^2 *value*	*p value*
Class I	19	5		30	11.642	0.003
	63.3%	16.7%	20.0%	100.0%		
Class II	6	12	12	30		
	20.0%	40.0%	40.0%	100.0%		
Total	25	17	18	60		
	41.7%	28.3%	30.0%	100.0%		

Table 4: Variation in airway volume among different skeletal patterns

	N	*Mean (mm³)*	*SD*	*Min. (mm³)*	*Max. (mm³)*	*'t' value*	*p value*
Class I	30	20733.2	6717.953	10,659	36,049	1.347	0.251
Class II	30	19032.2	4394.530	8,264	28,493		
Total	60	19882.7	5693.058	8,264	36,049		

Table 5: Comparison of airway volume among different genders

Skeleton pattern		*N*	*Mean*	*SD*	*Min.*	*Max.*	*'t' value*	*'p' value*
Class I	Male	9	17252.0	5137.170	10,659	24,674	3.784	0.062
	Female	21	22225.2	6862.420	14,014	36,049		
	Total	30	20733.2	6717.953	10,659	36,049		
Class II	Male	10	17317.8	4245.412	8,264	22,639	2.393	0.133
	Female	20	19889.4	4314.881	11,406	28,493		
	Total	30	19032.2	4394.530	8,264	28,493		

- In all the skeletal class I and class II subjects, the airway width > depth whereas, none of the skeletal class I and class II subjects had width ≤ depth. Depending on the width:depth ratio we subcategorised the wide type of airway morphology as; type I, type II and type III.
- In skeletal class I patients, distribution of type I airway morphology was more prominent compared to type II and type III whereas in skeletal class II patients, distribution of type II and III of airway morphology was more prominent compared to type I.

Clinical Significance

The present study used one of the novel imaging techniques CBCT, for analyzing the difference in morphology of skeletal class I and class II samples to provide the most accurate result. The age window of the samples is narrowed, and a standardization of gender was done which ensured a more reliable result. In this era of airway-centric treatment planning, this article acts as a stepping stone for understanding the uniqueness and diversity of airway among different individuals and thus plan Orthodontic treatment holistically so as to minimize treatment relapse.

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