Original Article

Assessment of maximal inspiratory and expiratory pressures in skeletal Class II patients with different growth patterns

Hita Rangarajan[a]; Irfan Ismail Ayub[b]; Sridevi Padmanabhan[c]

ABSTRACT

Objectives: To evaluate maximal inspiratory (MIP) and expiratory (MEP) pressures, which are reflective of respiratory muscle strength, in skeletal Class II patients with different growth patterns (horizontal, average, and vertical) and to correlate those with airway dimension.

Materials and Methods: Patients with a Class II skeletal base seeking orthodontic treatment were assigned to the following groups: average, horizontal, and vertical growth pattern. The control group (n = 14) comprised patients with a Class I skeletal base and average growth pattern. Airway dimensions were obtained using cone-beam computed tomography scans, and a spirometer with a pressure transducer was used for assessment of MIP and MEP. Routine spirometry for assessment of lung function was also performed.

Results: No significant differences were found in maximal inspiratory and expiratory pressures for the study groups in comparison with the control group. Class I patients had significantly greater oropharyngeal and nasopharyngeal airway volumes compared with the study groups. No significant difference in minimal cross-section area of the airway was observed among groups. A weak positive correlation between maximal inspiratory pressure and airway volume was observed.

Conclusions: Although Class I patients displayed significantly greater oropharyngeal and nasopharyngeal airway volumes, there was no significant difference in respiratory muscle strength or airway function between Class II patients with different growth patterns and the Class I control group. The findings underscore the significance of exploring factors beyond craniofacial growth patterns that may contribute to sleep-related breathing disorders. (*Angle Orthod*. 2024;94:328–335.)

KEY WORDS: Skeletal Class II malocclusion; Respiratory muscle strength; Airway dimensions; Growth patterns; Cone-beam computed tomography; Obstructive sleep apnea

INTRODUCTION

The relationship between craniofacial form and the airway has long been recognized, particularly in the context of sleep-related breathing disorders (SRBDs). It has been observed that certain morphological traits, such as mandibular retrognathia, narrow and deep palate, increased lower anterior facial height, inferior positioning of the hyoid bone, and reduced pharyngeal width, may predispose individuals to obstructive sleep apnea.[1–3]

Previous research has primarily focused on the association between airway morphology and craniofacial form, placing a greater emphasis on the sagittal[4–6] rather than the vertical dimension.[7–11] However, the link between sagittal or vertical malocclusion and airway dimension remains inconclusive. Multiple three-dimensional studies have evaluated changes in airway dimensions after functional appliance therapy, consistently demonstrating improvements.[12,13]

Alterations in airway morphology should not be automatically assumed to indicate a patent airway. Airway function depends largely on the resistance to airflow and, more importantly, on the efficiency of the respiratory muscles.[14] Healthy individuals have the ability to overcome an intrinsically narrow airway through active dilatation of the upper airway during inspiration.[15] Therefore, assessing measures of respiratory function such as

[a] Resident, Department of Orthodontics and Dentofacial Orthopaedics, Sri Ramachandra Institute of Higher Education and Research, Chennai, India.

[b] Professor, Department of Pulmonology, Sri Ramachandra Institute of Higher Education and Research, Chennai, India.

[c] Professor, Department of Orthodontics and Dentofacial Orthopaedics, Sri Ramachandra Institute of Higher Education and Research, Chennai, India.

Corresponding author: Prof Dr Sridevi Padmanabhan, No. 1 Ramachandra Nagar, Porur, Chennai 600116, India
(e-mail: sridevipadmanabhan@sriramachandra.edu.in)

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Table 1. General Information, Distribution of Participants[a]

	n	Mean Age, y	Gender (1, Females; 2, Males)	BMI, kg/m^2	STOP-Bang Score	ANB, °	SN-GoGN, °
Group 1 Class I (average)	14	25.14 ± 0.89	1.3571 ± 0.251	23.3143 ± 1.294	0.3571 ± 0.251	2.4286 ± 0.382	32.5714 ± 0.382
Group 2 Class II (horizontal)	15	20.4 ± 1.251	1.4 ± 0.248	23.4133 ± 1.311	0.6667 ± 0.302	6 ± 0.413	25.4 ± 1.009
Group 3 Class II (vertical)	14	23.5714 ± 2.83	1.5714 ± 0.259	20.9214 ± 1.664	0.5714 ± 0.326	6.9286 ± 0.873	36.6429 ± 1.936
Group 4 Class II (average)	14	21.5714 ± 1.745	1.4286 ± 0.259	22.2571 ± 1.86	0.5714 ± 0.259	6.4286 ± 0.43	32.3571 ± 0.251

[a] ANB indicates the angle formed between the cephalometric landmarks Point A, Nasion and Point B; BMI, body mass index, n, sample size; STOP-Bang (**S,** snoring; **T**, tiredness; **O**, observed apnea [witnessed pauses in breathing], **P**, blood pressure [high blood pressure]; **B**, body mass index [BMI]; **A**, age; **N**, neck circumference; **G**, gender.

respiratory muscle strength (RMS) and airflow becomes crucial in interpreting airway differences among various skeletal patterns. Maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) are a reflection of RMS and can be studied in a noninvasive manner.[16,17]

Given that skeletal Class II patterns are linked to reduced airway dimensions, this study aimed to assess RMS in patients with skeletal Class II malocclusion with varying vertical patterns. A normative control group consisting of Class I patients with an average growth pattern was included, and the study aimed to correlate RMS with airway dimensions evaluated using cone-beam computed tomography.

Objectives

This study had three objectives:

1. to evaluate and compare MIP and MEP in individuals with skeletal Class II malocclusion (horizontal, vertical, and average growth patterns) and a Class I control group (average growth pattern);
2. to evaluate and compare minimal cross-section area (MCA) and oropharyngeal, nasopharyngeal, and total airway volumes in individuals with skeletal Class II malocclusion (horizontal, vertical, and average growth patterns) and a Class I control group (average growth pattern); and
3. to correlate airway function and dimensions.

MATERIALS AND METHODS

Study Design and Ethical Approval

This cross-sectional, clinical study was approved by the Institutional Review Board at Sri Ramachandra Institute of Higher Education and Research (proposal No. CSP/21/JUL/96/394). Informed consent was obtained from all participants and their legal guardians for participation in the study. Written consent was also obtained from one participant for both participation as well as the publication of an identifying photograph. Consent was obtained in English as well as the local language.

Participants and Eligibility Criteria

Participants seeking orthodontic treatment at the postgraduate dental clinic of Sri Ramachandra Dental College were screened for this study. Patients between the ages of 17 and 35 years with a body mass index (BMI) $<$35 kg/m^2 were considered eligible to participate (Table 1).

Exclusion Criteria

Patients with craniofacial anomalies, disorders of respiratory function, sleep-related breathing disorders (screened using the STOP-Bang questionnaire),[18] allergies, deviated nasal septum, muscular dystrophy, or any muscle degenerative diseases were excluded from the study. Patients who had an acute respiratory infection 2 weeks prior to participation and those who had undergone any orthodontic treatment including growth modification, orthognathic surgery, or fixed appliance therapy were also excluded.

Clinical examination backed up by routine cephalometry was used to recruit patients and further categorize them into Class I and Class II malocclusions. The Class II patients were further subdivided into three groups based on their growth pattern (Supplementary Table 1). A total of 57 patients were recruited.

Sample Size Calculation

The required sample size was calculated as 14, based on a previous study,[19] with a power of 80% and an alpha error of 5%.

Measurement of RMS and Peak Expiratory Flow

A pulmonary function test system (Medical Equipment Europe, Hammelburg, Germany) was used (Figure 1a). The subjects were made to sit upright with the trunk at an angle of 90° to the hip and feet on the ground. A nose clip was used with a rigid mouthpiece that was adjusted according to the patient's height (Figure 1b). For the MIP measurement, the patient was asked to take a few normal breaths and then

Figure 1. (a) Pulmonary function test system for assessing the parameters of respiratory function. Medical Equipment Europe, Hammelburg, Germany. (b) Rigid mouthpiece for pulmonary function test system (c) Patient positioning with nose clip for assessing the parameters of respiratory function.

make a maximal inspiratory effort starting from the residual volume, and for MEP, a maximal expiratory effort starting from total lung capacity.[20,21] Three reproducible maneuvers were performed, each maintained for a duration of 2 seconds (Figure 1c). The patients were given a 1-minute rest between the efforts. The highest values were recorded for the data analysis (Figure 2).

Routine spirometry was also performed to assess lung function. From the values obtained, peak expiratory

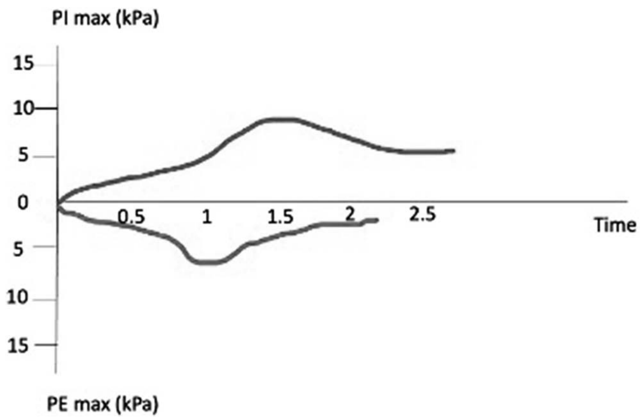

Figure 2. Peak inspiratory and expiratory pressure graphs. Obtained from the software for Medical Equipment Europe.

flow rate (PEF) and forced expiratory volume in 1 second (FEV1) were recorded.[22,23] The intraclass coefficient was greater than .8, showing good intraexaminer reliability.

Evaluation of Airway Dimension

Cone-beam computed tomography (Carestream Dental CS 9600, Carestream Health, Mumbai, India) was performed at Saveetha Dental College and Hospitals, India (Figure 3a). The patients were positioned with the orbital plane parallel to the floor. They were asked to refrain from swallowing during the scan and occlude in maximal intercuspation with the lips naturally closed and the tongue touching the palate. The scan was conducted at the end of expiration.[24,25]

Measurements

DICOM files were retrieved and imported into the Carestream software (Carestream Health).

The image was oriented and threshold selection was carried out by an oral and maxillofacial radiologist, following which, airway measurements were made. This was carried out using the airway analysis module of the software. The boundaries of the airway were automatically

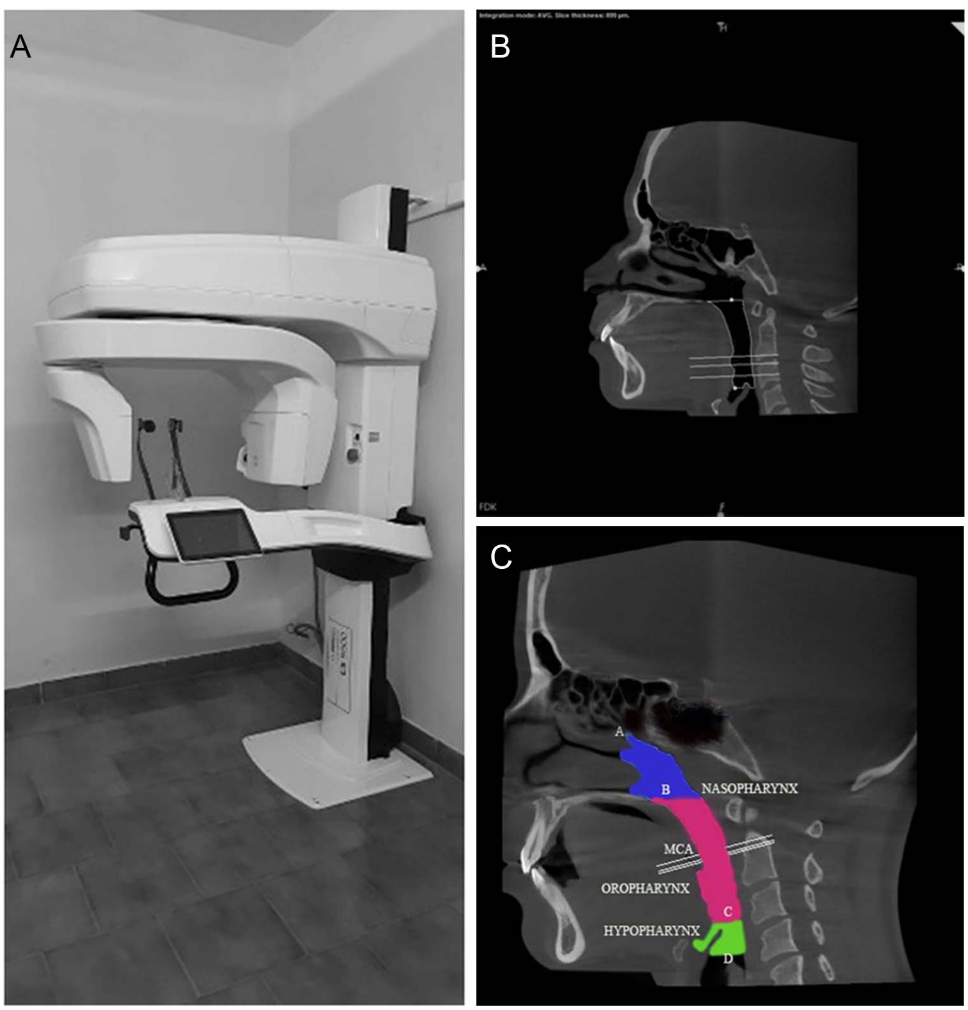

Figure 3. Cone-beam computed tomography machine (Carestream Health, Mumbai, India). (b) Region of interest for measurement of oropharyngeal airway (Carestream Health). (c) Boundaries for airway analysis (Carestream Health).

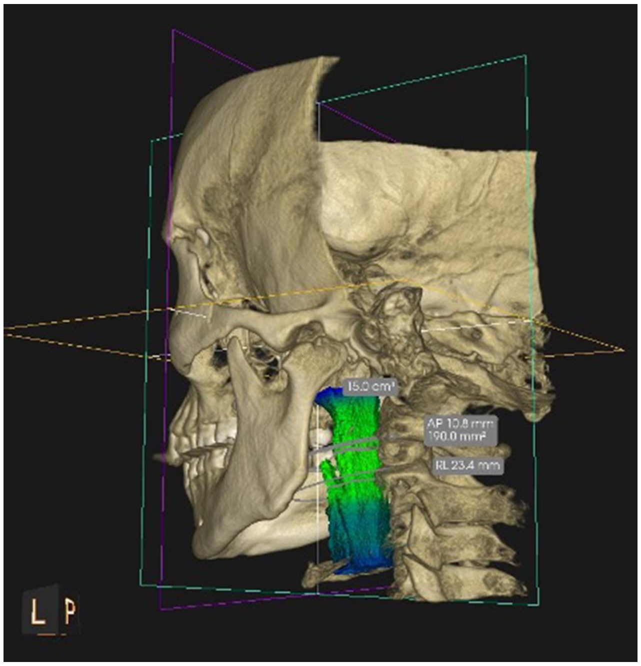

Figure 4. Three-dimensional rendering of airway volume and minimal cross-section area (Carestream Health).

detected in three dimensions once the region of interest was selected (Figure 3b). The protocol followed for determining the boundaries was in accordance with a previous study[24] (Figure 3c).

The nasopharyngeal, oropharyngeal, total airway volume (cubic millimeters) and the MCA (square millimeters) for the oropharynx were measured (Figure 4). The intraclass coefficient test for MCA measurement was .976 and for volume was .877.

Statistical Analysis

IBM SPSS Statistics 21.0 was used for all statistical analyses. Descriptive statistics including mean and standard deviation were used for MIP, MEP, PEF, oropharyngeal volume, and MCA. One-way analysis of variance (ANOVA) was used to detect statistically significant differences between all groups for MIP, MEP, PEF, oropharyngeal volume, and MCA. When a significant difference was detected ($P < .05$), the post hoc Tukey test was applied to make pairwise comparisons between the four groups. Pearson's correlation was used to correlate MIP, MEP, and PEF with oropharyngeal volume and MCA.

RESULTS

Descriptive statistics were used to analyze the distribution of participants and their cephalometric parameters (Table 1). ANOVA was used to identify significant differences among all groups, and a post hoc Tukey test was used to detect pairwise differences between the groups. The participants were matched for sex, BMI, and STOP-Bang score[18] (Supplementary Table 2 and 3).

Measures of Airway Function

Maximal inspiratory and expiratory pressures. Among the groups, the control group (group 1) exhibited the highest values of MIP and MEP. This was followed by groups 2, 3, and 4. The differences among the groups was not statistically significant (Table 2).

PEF, FEV1, and PEF/FEV1

The highest values of PEF were observed in the control group (group 1). Groups 3, 2, and 4 followed; however, the differences were not statistically significant (Table 2).

The control group exhibited the highest FEV1 values, followed by groups 2, 4, and 3. The differences were not statistically significant (Table 2).

Measures of Airway Dimension

Oropharyngeal volume. Oropharyngeal volume was highest in the control group (group 1). The values were significantly greater than that of groups 2, 3, and 4 (Table 3). Among the three experimental groups, no significant difference was observed (Supplementary Table 4).

Nasopharyngeal volume. Nasopharyngeal volume was also highest in the control group (group 1). The values were significantly greater than that of groups 2, 3, and 4 ($P < .05$; Table 3). Among the three experimental groups, group 2 exhibited the highest volume; however, this was not statistically significant (Supplementary Table 4).

Table 2. Comparison of Mean MIP, MEP, and PEF Among Groups[a]

	Group 1, kPa	Group 2, kPa	Group 3, kPa	Group 4, kPa	Comparison Among Groups, *P*
MIP	4.33 ± 1.44	3.70 ± 1.02	4.118 ± 0.85	3.77 ± 0.48	.536
MEP	4.70 ± 1.20	4.24 ± 1.10	4.08 ± 0.08	4.22 ± 0.708	.633
PEF	4.88 ± 0.70	4.69 ± 0.50	4.81 ± 1.09	4.33 ± 0.78	.79
FEV1	2.7957 ± 0.4	2.7227 ± 0.33	2.5664 ± 0.42	2.6463 ± 0.13	0.39
PEF/FEV1	1.8071 ± 0.247	1.7593 ± 0.144	1.78 ± 0.285	1.5529 ± 0.201	.42

[a] FEV1 indicates forced expiratory volume (in 1 second); kPa, kilo Pascals; MEP, maximal expiratory pressure; MIP, maximal inspiratory pressure; PEF, peak expiratory flow.

Table 3. Comparison of Airway Dimensions (Mean) Among Groups

	Class I; Average	Class II; Horizontal	Class II; Vertical	Class II; Average	*P* Value
Oropharyngeal volume, cm^3	20.05 ± 6.57	13.7 ± −4.09	13.86 ± 2.80	13.01 ± 3.13	.0002*
MCA[a], mm^2	239.2786 ± 39.28	189.3467 ± 30.237	220.04 ± 73.78	196.22 ± 61.04	.2067
Nasopharyngeal volume, cm^3	24.0071 ± 1.646	19.18 ± 2.461	18.3357 ± 1.462	18.3214 ± 2.691	.0001*
Total airway volume, cm^3	33.3857 ± 2.315	29.78 ± 3.202	30.3571 ± 3.062	32.4357 ± 3.361	.228

[a] MCA indicates minimal cross-sectional area.
* Statistically significant difference ($P < .05$).

Total airway volume. Total airway volume was highest in the control group (group 1). Group 4 had greater total volume than groups 2 and 3 did. The differences were not statistically significant (Table 3).

Minimal cross-section area. The MCA of the oropharyngeal region was found to be the highest in the control group (group 1), followed by groups 3, 4, and 2. The differences were not statistically significant (Table 3).

Correlation Between Airway Dimension and Function

Oropharyngeal, nasopharyngeal, and total airway volumes correlated positively with MIP, MEP, and PEF. The correlation was weak and statistically significant only for MIP and oropharyngeal volume ($P < .05$). The airway volumes correlated negatively with PEF/FEV1. This correlation was weak and not statistically significant (Table 4).

The MCA correlated positively with MIP and MEP and correlated negatively with PEF and PEF/FEV. This was weak and not statistically significant.

DISCUSSION

Historically, a strong correlation has been established between vertical growth pattern and the development of the upper airway. Studies have indicated that increased lower anterior facial height and a vertical growth pattern may contribute to an increased risk of SRBD.[1–3]

Due to growing concerns for SRBD, extensive research has been conducted on airway dimensions in patients with different craniofacial morphology. These studies have focused on the sagittal dimension, and while their findings varied, it is widely recognized that Class II malocclusion is generally associated with smaller airway dimensions.[4–6] Therefore, the current study set out to determine whether airway function followed the pattern of airway volume in Class II patients with emphasis on the vertical growth pattern.

MIP measures the strength of the diaphragm, scalene, and intercostal muscles, whereas MEP measures the strength of the abdominal and intercostal muscles involved in expiration. The maximal respiratory pressures also incorporate the elastic recoil of the lung and chest wall.[16,17]

The findings of the study indicated that MIP and MEP values fell within the normal range for healthy individuals in the local population.[18,19] No significant differences in MIP and MEP were observed between vertical, horizontal, and average Class II patients and the Class I control group with an average growth pattern. Although the control group had slightly higher values, the difference was not statistically significant. A plausible explanation for this is that all individuals in the study were healthy and did not have any signs of SRBD.

With regard to airway dimensions, the control group exhibited significantly greater oropharyngeal and nasopharyngeal volumes compared with the other groups (Class II). While some studies demonstrated a significant increase in airway dimensions in Class II individuals with different vertical patterns,[11] some others have shown the opposite effect.[9,10]

The current study found no significant differences in airway volumes among the three vertical skeletal patterns. In addition, there were no significant differences in the MCA between the control group and the groups with different growth patterns. Notably, the vertical growth pattern showed slightly higher MCA values than the control group

Table 4. Correlation Between Airway Dimensions and Airway Function in All Groups[a]

	MIP, *r*	MEP, *r*	PEF, *r*	PEF/FEV1, *r*
Oropharyngeal volume, cm^3	.3*	.02	.05	−.04
Nasopharyngeal volume	.1	.2	.1	−.1
Total airway volume	.1	.1	.2	−.1
Minimal cross-section area, mm^2	.06	.02	−.04	−.1

[a] FEV1 indicates forced expiratory volume in 1 second; MEP, maximal expiratory pressure; MIP, maximal inspiratory pressure; PEF, peak expiratory flow; *r*, Pearson's correlation coefficient.
* Statistically significant difference ($P < .05$).

did. Previous studies also reported no significant differences in MCA between Class I and Class II patients.[5]

No significant correlation was observed in this study between MIP, MEP, and airway dimensions (volumes and MCA). This was the first study to correlate these parameters in healthy skeletal Class II individuals with various vertical growth patterns. A previous study found a weak but significant positive correlation between muscle strength and airway dimension after maxillary expansion treatment.[14]

In summary, this study confirmed previous findings of reduced airway dimensions in skeletal Class II patients compared with Class I patients. However, no significant differences in airway dimensions were observed among Class II patients with different growth patterns. Of greater clinical importance was that there were no significant differences in respiratory function and no correlation between airway dimension and RMS or PEF.

These findings imply that sleep-related breathing disorders may be influenced by factors beyond the scope of craniofacial growth patterns.

Respiratory muscles and the soft tissue lining of the pharyngeal wall play a crucial role in maintaining airway patency in SRBD. It has been suggested that the effectiveness of these muscles can compensate for compromises in airway dimensions. Sleep apnea phenotyping has identified both anatomic and nonanatomic phenotypes, which implies that altered craniofacial morphology does not automatically predispose to SRBD. The findings of this study reinforce this and stress the importance of functional studies of the muscles that line the airway.[14,15] To study these muscles, invasive methods such as electromyography would be required. This is likely why previous studies have focused on MIP and MEP to study airway function.[16,26]

The inherent limitation of this study was the inability to examine these muscles without using invasive tests, which would establish without doubt the relationship between airway function and dimension.

CONCLUSIONS

- **RMS:** No significant differences were found in RMS (measured as MIP and MEP) among Class II patients with different growth patterns and a Class I control group with an average growth pattern.
- **Airway dimensions:** Class I patients with an average growth pattern displayed significantly greater oropharyngeal and nasopharyngeal airway volumes compared with Class II patients with various growth patterns.
- **Correlation between airway dimensions and RMS:** A weak positive correlation was observed between MIP and airway volume, particularly in the oropharyngeal region. However, no clear link could be established between airway dimensions and respiratory muscle function in healthy individuals.

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SUPPLEMENTAL DATA

Supplemental Tables 1, 2, 3, and 4 are available online.

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