Pharyngeal airway evaluation following isolated surgical mandibular advancement: A 1-year follow-up

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Introduction: The aim of this study was to evaluate the stability of pharyngeal airway space changes with the use of acoustic pharyngometry 1 year after bilateral sagittal split ramus osteotomy for mandibular advancement in patients with skeletal Class II malocclusion. **Methods:** The sample comprised 16 patients (mean age 21.26 ± 1.86 years). Acoustic pharyngometry measurements were recorded 1 week before surgery (T0), 2 months after surgery (T1), and 1 year after surgery (T2). Parameters were compared by means of repeated-measures analysis of variance (ANOVA). **Results:** Significant increase was seen in minimum cross-sectional area 2 months after surgery ($P < 0.001$). Relapse of 12.6% was observed within 1 year after surgery ($P < 0.001$). Statistically significant increase, ie, 31.5%, was seen in mean cross-sectional area 2 months after surgery ($P < 0.001$), which relapsed by 7.9% 1 year after surgery ($P < 0.001$). Significant increase in mean volume from 30.32 ± 2.2 cm^3 before surgery to 38.91 ± 2.73 cm^3 2 months after surgery ($P < 0.001$) was observed. Mean volume relapsed 3.9% 1 year after surgery ($P < 0.001$). **Conclusion:** Changes in pharyngeal airway space dimensions in patients subjected to isolated surgical mandibular advancement on 1 year follow up showed encouraging results. (Am J Orthod Dentofacial Orthop 2019;155:207-15)

Airway plays a vital role in our daily sustenance. An integral part of the facial complex, any changes in the orientation of the hard and soft tissues would also cause a change in the upper airway. Over the past 2 decades, extensive research has been carried out to evaluate and correlate the skeletal relationships, dimensions of pharyngeal airway space, and orthognathic surgical procedures. Individuals with a skeletal Class II relationship are known to have reduced upper airway dimensions compared with patients with Class I and Class III skeletal relationships,[1] owing to the downward and backward positioning of the mandible, causing some amount of upper airway constriction.

Surgical advancement of a retrognathic mandible by means of bilateral sagittal split ramus osteotomy (BSSRO) has proven to be highly successful in increasing the dimensions of the pharyngeal airway.[2,3] Hernandez-Alfaro et al[4] demonstrated an increase of 78.3% in the pharyngeal airway, and other researchers reported an increase of 40%-50% after only 2-4 months following surgical mandibular advancement.[2,5,6]

In the past, lateral cephalography has been extensively used for evaluating postoperative changes. However, it has an inherent limitation of permitting measurements only in the sagittal plane with multiple overlapping of structures and assessing a 3-dimensional (3D) structure in 2 dimensions.[7] These limitations were overcome to a certain extent by the use of cone-beam computerized tomography (CBCT), which permits 3D evaluation of the pharyngeal airway system, including volumetric investigation,[8] and was found to be highly effective in evaluating the pharyngeal airway space.[9] Though reliable, CBCT has limitations regarding radiation exposure and inability to discriminate fine layers of various soft tissues structures, which can lead to inaccurate conclusions.[10] Acoustic pharyngometry, a noninvasive diagnostic tool, also has been used for evaluation of the upper airway. Pharyngometry makes use of sound waves and works on a principle similar to a ship's SONAR system. It analyzes sound

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waves reflected from the airway by transforming their phase and amplitude information into an area-distance relationship[11] and is an effective tool for quantifying the pharyngeal airway space.[12,13] The airway being a dynamic structure, acoustic pharyngometry may be more effective than CBCT in evaluating the pharyngeal airway system because it provides real-time display of the airway by taking readings at 0.2-second intervals during function, which is a more relevant assessment.

Numerous studies have evaluated long-term changes in the pharyngeal airway after dual-jaw surgeries, but no study has evaluated changes produced by isolated surgical mandibular advancement on 1 year follow-up with the use of dynamic registration, such as acoustic pharyngometry.[14-16] Current data available from cephalography-based studies on postsurgical airway changes are debatable regarding their reliability and reproducibility. Achilleos et al[17] found an increase in pharyngeal airway space to be stable on 3-year follow-up, but Farole et al[18] and Yu et al[19] observed significant relapse in pharyngeal airway space on long-term follow-up.

The present study was carried out with the aim to evaluate the stability of pharyngeal airway space changes with the use of acoustic pharyngometry in adult patients with skeletal Class II malocclusion managed by combined orthodontic-surgical treatment for mandibular advancement by means of BSSRO.

MATERIAL AND METHODS

This prospective study was carried out on selected patients who visited the orthodontic department of a tertiary care institution from January 2015 to June 2017. Sample calculation was performed based on a previously published study,[20] and a sample size of 16 was found to be adequate. Sixteen patients of mixed Indian population, planned to be treated with BSSRO for mandibular advancement, were invited to be part of the study after informed consent. The research proposal was approved by the Institutional Research Ethics Committee. Presurgical ages of subjects ranged from 18 to 25 years, and the sample included 9 men and 7 women. Patients included in the study fulfilled the following inclusion criteria; skeletal Class II malocclusion due to mandibular retrognathism, dental Angle Class II Divison 1 malocclusion, and body mass index (BMI) > 25 kg/m². Patients with temporomandibular disorder, previous craniofacial surgeries, syndromic cases, and systemic disorders were excluded from the study. All subjects had fixed orthodontic appliances before surgery to align, level, and coordinate the dental arches. All underwent

Table I. Descriptive statistics of the patients

Number	*16 (9 male, 6 female)*
Age (y)	21.26 ± 1.86
Body mass index (kg/m²)	
Male	23.2 ± 1.8
Female	21.9 ± 2.1
ANB (°)	6.8 ± 0.65
SNB (°)	74.56 ± 1.2
Facial angle (°)	77.5 ± 1.67

mandibular advancement surgery by means of BSSRO that moved the distal fragment of the mandible downward and forward along the occlusal plane. After surgery, all subjects had finishing orthodontics for an average of 4.5 months. All patients were operated on by the same surgeon, and none of them underwent advancement more than 7 mm. After debonding, all subjects were given wraparound retainers with anterior bite plane in the upper arch and fixed spiral wire retainers in the lower arch and kept on a retention protocol with periodic visits. Mean age, BMI, and cephalometric characteristics are described in Table I.

All patients were subjected to acoustic pharyngometry for assessment of cross-sectional area (CSA) and volume of pharyngeal airway space. Acoustic pharyngometry examinations were performed with the use of the Ecovision acoustic pharyngometer (Sleep Group Solutions, Hollywood, Fla). Unlike anatomic imaging modalities, acoustic pharyngometry is limited to providing measurements of CSA and volume according to distance along the airway; it does not provide high resolution imaging of anatomic or soft tissue structures. This system measures CSA and volume from the oral cavity to the hypopharynx by evaluating changes in acoustic impedance with the use of computer software.

The acoustic pharyngometer records readings at 0.2-second intervals. However, it is only after a number of such repeated measurements that an average graph of these dynamically observed readings is produced by the software. In addition to this, the graph, while being recorded, shows the superimposition on subsequent readings in a form of waves, which when they are spread apart indicate improper recording whereas when overlapped they indicate proper recording. The final acoustic pharyngometer graph produced is in itself a depiction of a mean of these multiple repeated measurements carried out during the dynamic (functional) state of pharyngeal airway.

All the recordings were made with the patient in the sitting position, back straight and the head and neck in a natural head position, as described by the manufacturer.[21] A Free Flow mouthpiece (Sensor Medics
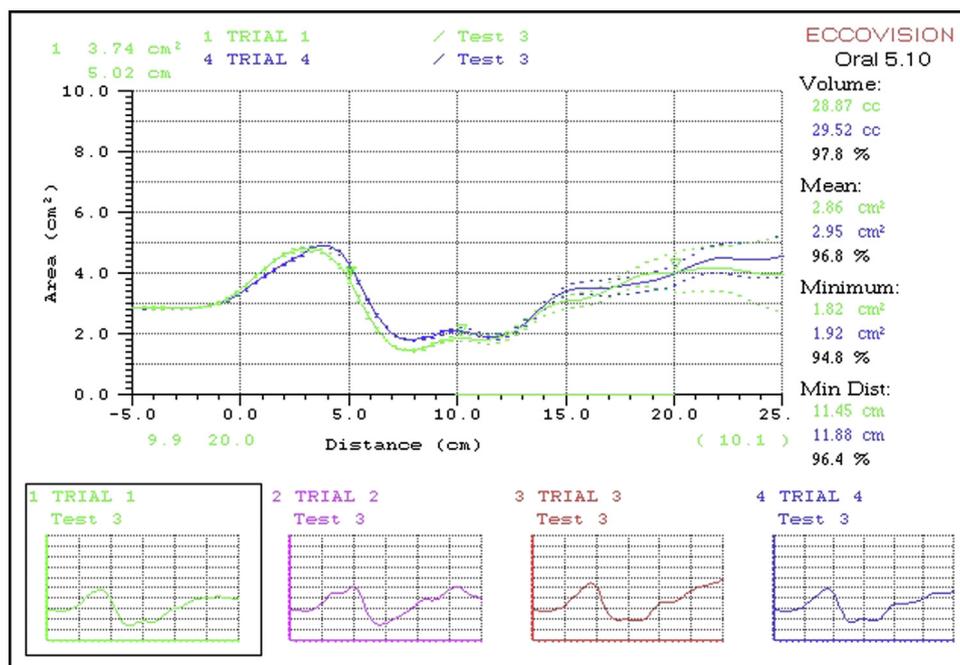
Fig 1. Acoustic pharyngometry measurements at T0 (before surgery).

Corporation, Yorba Linda, Calif) was used during the study. Subjects were instructed to place their teeth against the flange of the mouthpiece, biting down on the protruding tabs, tongue under the cross bar, and to make a lip seal over the flange and breath normally while measurements were recorded. The mouthpiece aided in reproducing bite position and stabilizing the tongue. The tube was held parallel to the floor by the assistant. Acoustic pharyngometry measurements were recorded 1 week before surgery (T0), 2 months after surgery (T1), and 1 year after surgery (T2; Figs 1-3). For every subject, measurements were recorded 4 times on each occasion to calculate the coefficient of variance.[22] A coefficient of variance >10% was considered to be poorly reproducible and the acoustic pharyngometry tracing and measurements were repeated. This improved the accuracy of the recorded measurements. Reliability measures were determined by randomly selecting 10 subjects and repeating presurgical acoustic pharyngometry recordings 1 week after the initial measurements. Pretreatment, BSSRO, posttreatment, and 1-year follow-up photographs of a representative case are depicted in Figures 4-7.

Statistical analysis

The data collected were compiled in an Excel spreadsheet (Microsoft, Redmond, Wash) and transferred to SPSS version 22.0 software (SPSS, Chicago, Ill). Intraclass correlation coefficient (ICC) was used to determine reliability of measurements recorded. ICC values closer to 1 indicate reliability between measurements. Means and SDs were calculated. The presurgical (T0), 2-month postsurgical (T1), and 1-year postsurgical (T2) measurements were compared by means of repeated-measures analysis of variance ANOVA. $P < 0.05$ was considered to be statistically significant.

RESULTS

Patient age and sex showed no difference in distribution ($P > 0.05$). The mean mandibular advancement was 5.87 ± 0.81 mm (range 5-7 mm) (Table II). The mean age of the sample was 21.26 ± 1.86 years. The relationship of mandible to cranial base, ie, the SNB angle, increased by $5.45 \pm 2.69°$ after surgery. Reliability measures were determined by repeating presurgical acoustic pharyngometry recordings 1 week after the initial measurements. ICCs of 0.90 for intraexaminer and 0.88 for interexaminer measurements demonstrated high reliability. The results of repeated-measures ANOVA for the comparison of presurgical (T0), 2-months postsurgical (T1), and 1-year postsurgical (T2) measurements are presented in Table III.

Significant increase was seen in minimum CSA 2 months after surgery ($P < 0.001$). It increased by 0.71 cm^2, but a reduction from that of 0.31 cm^2 was noticed 1 year after surgery ($P < 0.001$). Statistically
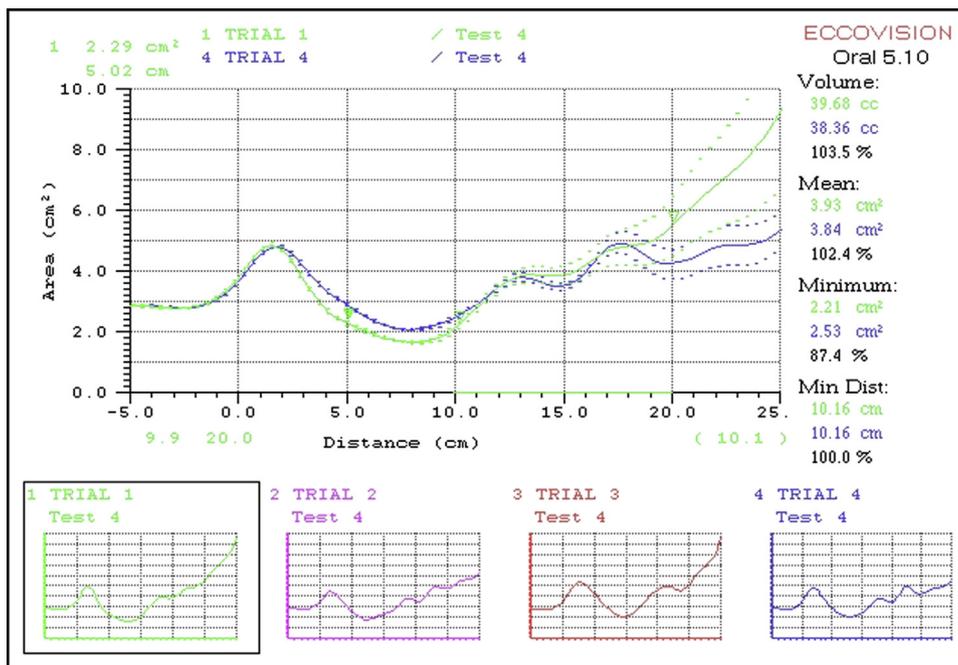
Fig 2. Acoustic pharyngometry measurements at T1 (2 months after surgery).
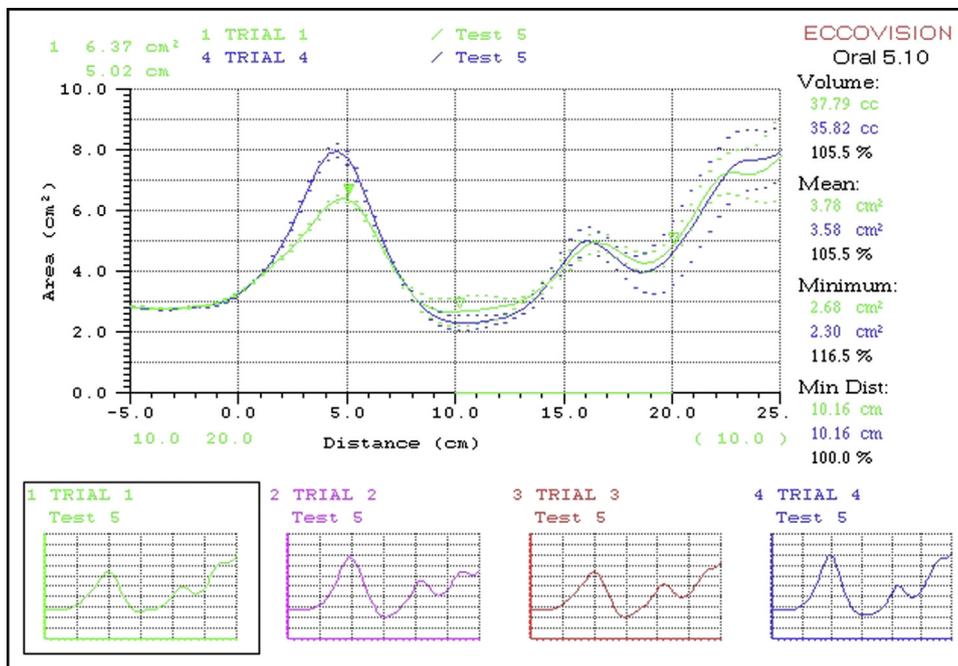

Fig 3. Acoustic pharyngometry measurements at T2 (1 year after surgery).

significant increase was seen in mean CSA 2 months after surgery ($P < 0.001$). It increased by 31.5%, but a relapse of 7.9% was observed 1 year after surgery ($P < 0.001$). Surgical mandibular advancement by means of BSSRO resulted in significant increase of mean volume from 30.32 ± 2.2 cm^3 before surgery to 38.91 ± 2.73 cm^3 2 months after surgery ($P < 0.001$). Mean volume decreased to 37.41 ± 2.66 cm^3 1 year after
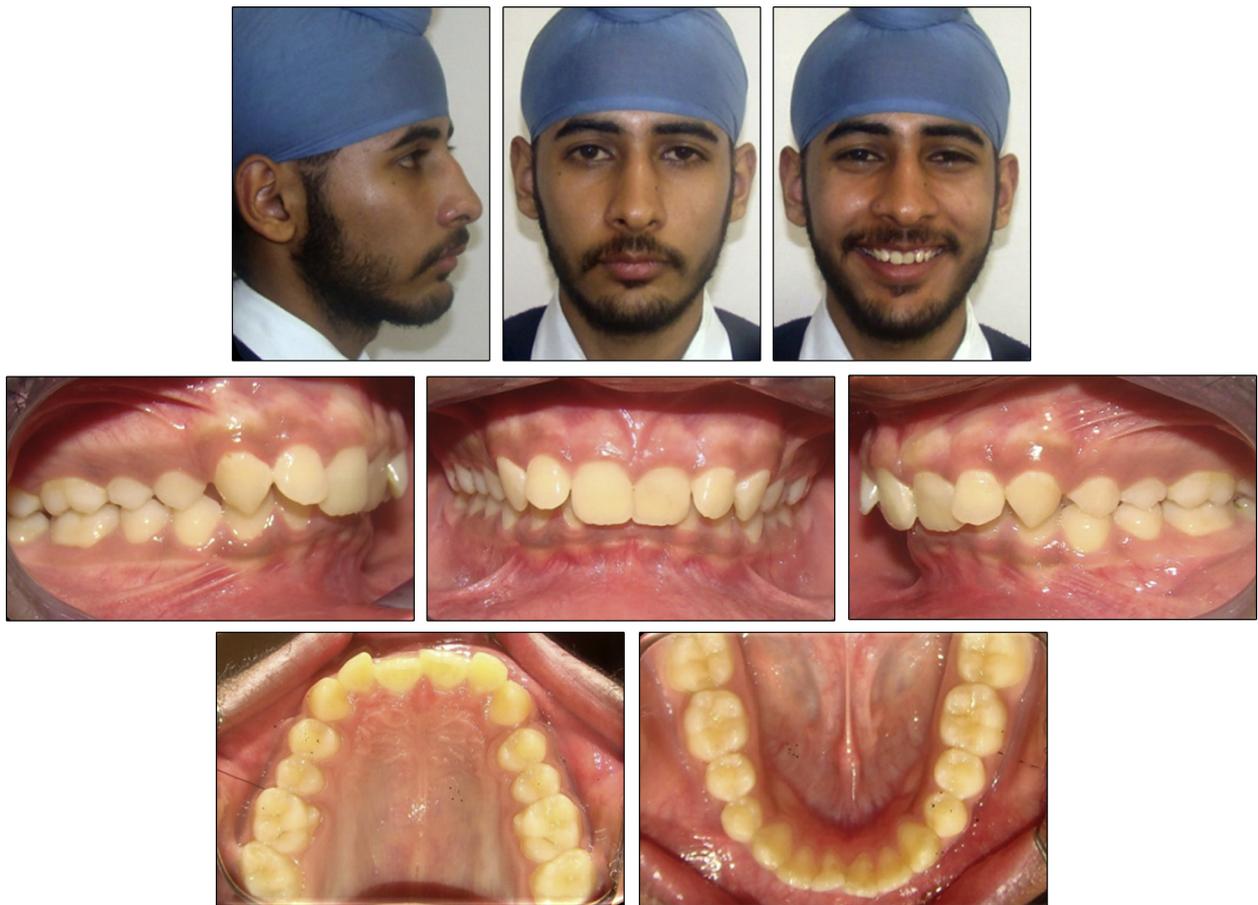
Fig 4. Representative pretreatment facial and intraoral photographs.

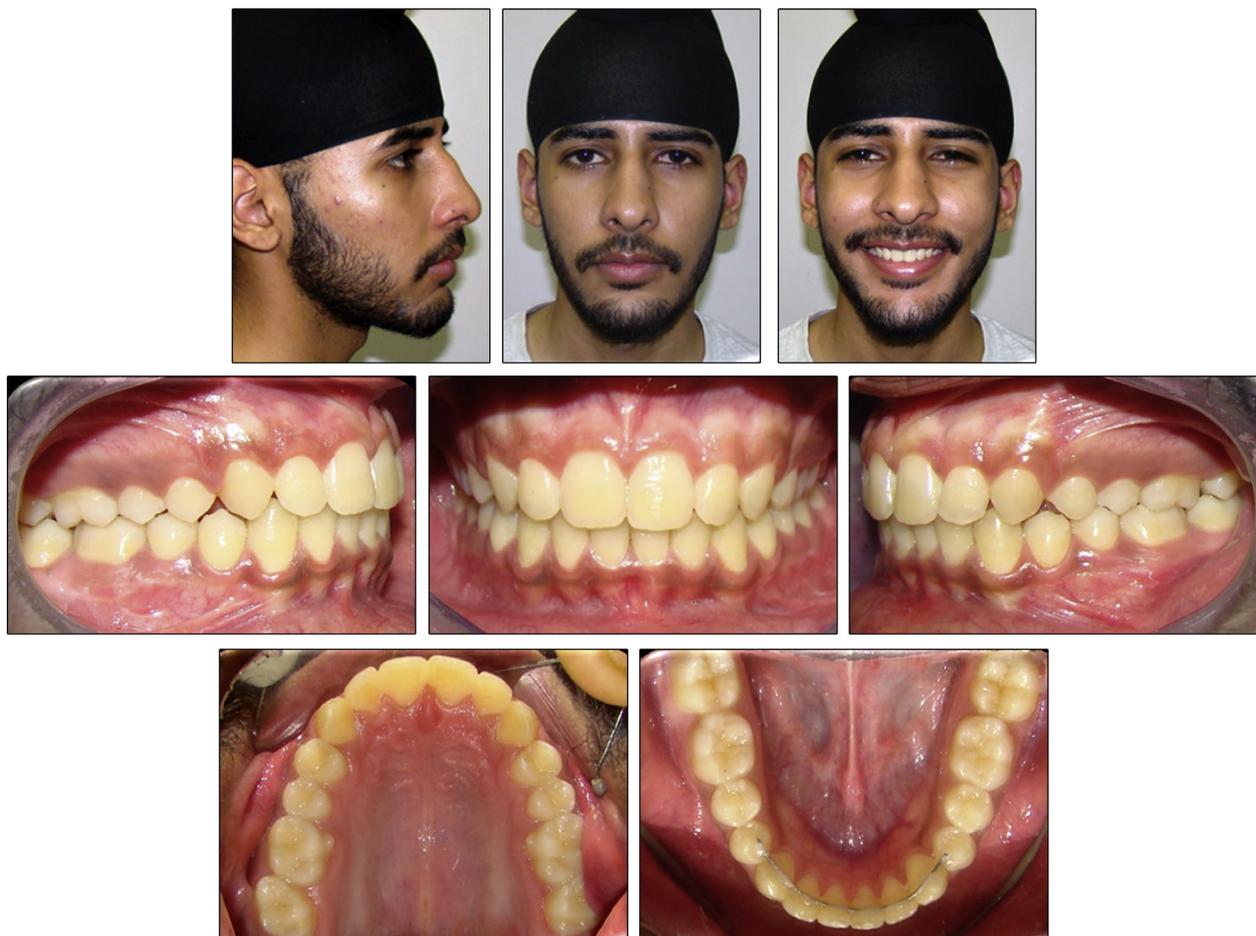**Fig 5.** Representative BSSRO photographs.

Fig 6. Representative posttreatment facial and intraoral photographs.

surgery, representing a relapse of 3.9% ($P < 0.001$). There were no losses to follow-up in this study.

DISCUSSION

This study evaluated the stability of changes in pharyngeal airway space dimensions over a period of 1 year with the use of acoustic pharyngometry in subjects of Class II malocclusion who underwent surgical mandibular advancement by means of BSSRO. The airway being a soft tissue tubular structure, it needs to be evaluated in a dynamic state and in all 3 planes of space. Acoustic pharyngometry, a noninvasive diagnostic tool, permits dynamic evaluation of the airway.[12] It has advantages of being noninvasive and providing immediate graphic and numeric display of results. Its reproducibility and reliability as a diagnostic aid for airway evaluation have been evaluated extensively.[23]

Unlike other 3D imaging technologies, acoustic pharyngometry does not provide high resolution imaging of anatomic structures. Therefore, there is no need to segment the airway as required with the use of computerized tomography and magnetic resonance imaging. It makes use of sound waves to generate a pharyngogram that is a direct representation of the anatomy of the oral cavity and pharynx. The oropharyngeal junction is always at a distance of 5-8 cm on the x-axis of the pharyngogram.[22]

To permit complete resolution of postsurgical soft tissue edema, measurements were recorded 2 months after surgery. Because pharyngeal airway space dimensions are known to be altered by the position of the head as well as respiration,[24,25] patients were asked to keep their head in the natural head position to achieve high reproducibility. Tongue position was standardized with the use of a mouthpiece, and measurements were recorded during relaxed normal breathing. A protocol similar to that of Tsolakis et al[26] was used to record acoustic pharyngometry measurements. Farole et al[18]

Fig 7. Representative 1-year follow-up facial and intraoral photographs.

Table II. Mandibular advancement (mm) in patients subjected to BSSRO

Patient	Mandibular advancement
1	5
2	6
3	5
4	5
5	6
6	7
7	6
8	6
9	7
10	5
11	7
12	6
13	7
14	6
15	5
16	5

found that immediate postoperative pharyngeal airway space dimensions of 3.56 mm decreased to 2.68 mm over a long-term follow up of 4 years. They concluded that although increase in pharyngeal airway space

occurs on surgical mandibular advancement, results are highly variable and unpredictable in the long term. Sears et al[27] observed relapse of pharyngeal airway space dimensions within 6 months after surgery. Chang et al,[28] with the use of CBCT found that airway volume increased by 34.6% immediately after surgery (T1 − T0) but decreased to 15% within 6 months after surgery (T2 − T0). In the present study, 2 months after surgery (T1 − T0) the change in pharyngeal airway space volume was 28.3%, which decreased to 23.4% at 1 year after surgery (T2 − T0), a relapse of only ∼4%, which could be considered stable and a positive change.

CSA plays a vital role in sleep disordered breathing because it offers maximum resistance to airflow.[29] Keeping this in mind, changes in minimum CSA also were evaluated in the present study. The average minimum CSA in patients with skeletal Class II malocclusion is 1.62 cm^2, which is in agreement with the findings of our study. It was interesting to note that maximum relapse over a 1-year follow-up, ie, 12.6%, was observed in minimum CSA compared with mean CSA and mean volume of pharyngeal airway space. The present study

Table III. Minimum cross-sectional area (CSA), mean CSA, and mean volume of pharyngeal airway system

Parameter	Time point	Mean	SD	P value			Mean change			Percentage change			Change per mm advancement		
				T1 – T0	T2 – T1	T2 – T0	T1 – T0	T2 – T1	T2 – T0	T1 – T0	T2 – T1	T2 – T0	T1 – T0	T2 – T1	T2 – T0
Minimum CSA (cm²)	T0	1.75	0.41	0.001	0.001	0.001	0.71	−0.31	0.40	40.5	−12.6	22.9	0.12	−0.05	0.07
	T1	2.46	0.65												
	T2	2.15	0.55												
Mean CSA (cm²)	T0	2.79	0.54	0.001	0.001	0.001	0.88	−0.29	0.59	31.5	−7.9	21.1	0.15	−0.05	0.10
	T1	3.67	0.45												
	T2	3.38	0.42												
Mean volume (cm³)	T0	30.32	2.20	0.001	0.001	0.001	8.59	−1.5	7.09	28.3	−3.9	23.4	1.47	−0.26	1.21
	T1	38.91	2.73												
	T2	37.41	2.66												

P values according to repeated-measures analysis of variance.

has demonstrated that soft tissues surrounding the airway have a tendency to regress to some extent, though not completely to their presurgical position.

Chang et al[28] carried out mean mandibular advancement of 8 mm (range 5-15 mm), and Valladares-Neto et al's[30] sample had an average mandibular advancement of 5 mm (range 4-10 mm). Subjects in the present study had mean mandibular advancement of 5.86 ± 0.83 mm (range 5-7 mm). According to Samchukov et al,[31] mandibular advancement of <7 mm should be managed surgically with the use of BSSRO and >7 mm with the use of distraction osteogenesis, to take advantage of distraction histogenesis of the soft tissues. Each 1 mm of advancement resulted in an increase of minimum CSA by 0.12 cm², of mean CSA of 0.15 cm², and of mean volume of 1.47 cm³ on 2-month follow-up. Similar results were achieved by Kochar et al[2] on 5-month follow-up after mandibular advancement.

Results of our study were contrary to those shown by Eggensperger et al.[20] In a 12-year-long cephalography-based follow-up study, they observed that increase in pharyngeal airway space dimensions after surgical mandibular advancement is not stable. They found relapse of 4-5 mm in sagittal dimensions, resulting in reduction of pharyngeal airway space dimensions to less than the preoperative size. They observed that pharyngeal airway space dimensions relapsed to baseline changes within 14 months after surgery, whereas in our study relapse (T2 − T1) of minimum CSA was 12.6%, of mean CSA 7.9%, and of mean volume 3.9%. Although the relapse observed in our study is statistically significant, it is not significant clinically.

In this study, dynamic evaluation of the pharyngeal airway space was done over a period of 1 year after orthosurgical treatment. The results could serve as a baseline for carrying out similar studies with a long-term follow-up and with a larger sample size.

CONCLUSIONS

One-year follow-up of the stability of changes in pharyngeal airway space dimensions in patients subjected to isolated surgical mandibular advancement has shown encouraging results. Relapses observed in minimum CSA, mean CSA, and mean volume were 12.6%, 7.9%, and 3.9%, respectively, which were clinically insignificant. Acoustic pharyngometry is a noninvasive diagnostic tool that provides real-time imaging of the pharyngeal airway space. Use of this noninvasive tool in routine dental practice permits clinicians to readily screen the upper airway of patients with skeletal malocclusion.

REFERENCES

1. El H, Palomo JM. Airway volume for different dentofacial skeletal patterns. Am J Orthod Dentofacial Orthop 2011;139:e511-21.

2. Kochar GD, Chakranarayan A, Kohli S, Kohli VS, Khanna V, Jayan B, et al. Effect of surgical mandibular advancement on pharyngeal airway dimensions: a three-dimensional computed tomogracoustic pharyngometry study. Int J Oral Maxillofac Surg 2016;45:553-9.

3. Sahoo NK, Jayan B, Ramakrishna N, Chopra SS, Kochar GD. Evaluation of upper airway dimensional changes and hyoid position following mandibular advancement in patients with skeletal Class II malocclusion. J Craniofac Surg 2012;23:e623-7.

4. Hernández-Alfaro F, Guijarro-Martínez R, Mareque-Bueno J. Effect of mono- and bimaxillary advancement on pharyngeal airway volume: cone-beam computed tomogracoustic pharyngometryy evaluation. J Oral Maxillofac Surg 2011;69:e395-400.

5. Kochel J, Meyer-Marcotty P, Sickel F, Lindorf H, Stellzig-Eisenhauer A. Short-term pharyngeal airway changes after mandibular advancement surgery in adult Class II-patients—a three-dimensional retrospective study. J Orofac Orthop 2013;74:137-52.

6. Turnbull NR, Battagel JM. The effects of orthognathic surgery on pharyngeal airway dimensions and quality of sleep. J Orthod 2000; 27:235-47.

7. Abramson ZR, Susarla S, Tagoni JR, Kaban L. Three-dimensional computed tomogracoustic pharyngometryic analysis of airway anatomy. J Oral Maxillofac Surg 2010;68:363-71.

8. Scarfe WC, Farman AG. What is cone-beam CT and how does it work? Dent Clin North Am 2008;52:707-30.

9. Yamashina A, Tanimoto K, Sutthiprapaporn P, Hayakawa Y. The reliability of computed tomogracoustic pharyngometryy (CT) values and dimensional measurements of the oropharyngeal region using cone beam CT: comparison with multidetector CT. Dentomaxillofac Radiol 2008;37:245-51.

10. Park SB, Kim YI, Son WS, Hwang DS, Cho BH. Cone-beam computed tomogracoustic pharyngometry evaluation of short- and long-term airway change and stability after orthognathic surgery in patients with Class III skeletal deformities: bimaxillary surgery and mandibular setback surgery. Int J Oral Maxillofac Surg 2012;41:87-93.

11. Goldberg AN, Schwab RJ. Identifying the patient with sleep apnea: upper airway assessment and physical examination. Otolaryngol Clin North Am 1998;31:919-30.

12. Kamal I. Test-retest validity of acoustic pharyngometry measurements. Otolaryngol Head Neck Surg 2004;130:223-8.

13. d'Urzo AD, Rubinstein I, Lawson VG, Vassal KP, Rebuck AS, Slutsky AS, et al. Comparison of glottic areas measured by acoustic reflections vs computerized tomogracoustic pharyngometryy. J Appl Phys 1988;64:367-70.

14. Chen F, Terada K, Hua Y, Saito I. Effects of bimaxillary surgery and mandibular setback surgery on pharyngeal airway measurements in patients with Class III skeletal deformities. Am J Orthod Dentofacial Orthop 2007;131:372-7.

15. Goncalves JR, Buschang PH, Goncalves DG, Wolford LM. Postsurgical stability of oropharyngeal airway changes following counterclockwise maxillomandibular advancement surgery. J Oral Maxillofac Surg 2006;64:755-62.

16. Marsan G, Vasfi Kuvat S, Oztas E, Cura N, Süsal Z, Emekli U. Oropharyngeal airway changes following bimaxillary surgery in Class III female adults. J Craniomaxillofac Surg 2009;37:69-73.

17. Achilleos S, Krogstad O, Lyberg T. Surgical mandibular advancement and changes in uvuloglossopharyngeal morphology and head posture: a short- and long-term cephalometric study in males. Eur J Orthod 2000;22:367-81.

18. Farole A, Mundenar MJ, Braitman LE. Posterior airway changes associated with mandibular advancement surgery: implications for patients with obstructive sleep apnea. Int J Adult Orthodon Orthognath Surg 1990;5:255-8.

19. Yu LF, Pogrel MA, Ajayi M. Pharyngeal airway changes associated with mandibular advancement. J Oral Maxillofac Surg 1994;52: 40-3.

20. Eggensperger N, Smolka K, Johner A, Rahal A, Thüer U, Iizuka T. Long-term changes of hyoid bone and pharyngeal airway size following advancement of the mandible. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005;99:404-10.

21. Eccovision acoustic pharyngometry system: operator manual. Hollywood, Fla: Sleep Group Solutions; 2015. p. 9-10.

22. Kamal I. Normal standard curve for acoustic pharyngometry. Otolaryngol Head Neck Surg 2001;124:323-30.

23. Marshall I, Maran NJ, Martin S, Jan MA, Rimmington JE, Best JJ, et al. Acoustic reflectometry for airway measurements in man: implementation and validation. Physiol Meas 1993;14:157-69.

24. Pirilä-Parkkinen K, Löppönen H, Nieminen P, Tolonen U, Pääkkö E, Pirttiniemi P. Validity of upper airway assessment in children: a clinical, cephalometric, and MRI study. Angle Orthod 2011;81:433-9.

25. Brunetto DP, Velasco L, Koerich L, Araújo MT. Prediction of 3-dimensional pharyngeal airway changes after orthognathic surgery: a preliminary study. Am J Orthod Dentofacial Orthop 2014;146:299-309.

26. Tsolakis IA, Venkat D, Hans MG, Alonso A, Palomo JM. When static meets dynamic: comparing cone-beam computed tomogracoustic pharyngometryy and acoustic reflection for upper airway analysis. Am J Orthod Dentofacial Orthop 2016;150:643-50.

27. Sears CR, Miller AJ, Chang MK, Huang JC, Lee JS. Comparison of pharyngeal airway changes on plain radiogracoustic pharyngometryy and cone-beam computed tomogracoustic pharyngometry after orthognathic surgery. J Oral Maxillofac Surg 2011;69: e385-94.

28. Chang MK, Sears C, Huang JC, Miller AJ, Kushner HW, Lee JS. Correlation of airway volume with orthognathic surgical movement using cone-beam computed tomogracoustic pharyngometryy. J Oral Maxillofac Surg 2015;73(12 Suppl):S67-76.

29. El H, Palomo JM. An airway study of different maxillary and mandibular sagittal positions. Eur J Orthod 2013;35:262-70.

30. Valladares-Neto J, Silva MA, Bumann A, Paiva JB, Rino-Neto J. Effects of mandibular advancement surgery combined with minimal maxillary displacement on the volume and most restricted cross-sectional area of the pharyngeal airway. Int J Oral Maxillofac Surg 2013;42:1437-45.

31. Samchukov MI, Cope JB, Cherkashin AM. Craniofacial distraction osteogenesis. Saint Louis: Mosby; 2007.