Linear and Volumetric Airway Changes After Maxillomandibular Advancement for Obstructive Sleep Apnea

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Purpose: Maxillomandibular advancement (MMA) surgery is a well-established treatment of obstructive sleep apnea (OSA). Although many studies have assessed the efficacy of MMA in treating OSA, very few studies have quantified the magnitude of its changes to airway morphology. Therefore, the present study investigated the linear and volumetric morphologic changes that occur in the pharyngeal airway after treatment of OSA using MMA.

Materials and Methods: A retrospective cohort study of patients with OSA treated from May 2010 to February 2014 was performed. Each patient underwent preoperative clinical and fiberoptic nasopharyngoscopic examinations. Pre- and postoperative polysomnograms, lateral cephalograms, and cone-beam computed tomography scans were acquired. The radiographic images were used to determine the linear and volumetric airway measurements. The time and magnitude of skeletal movement were used as the independent variables. The dependent variables included assessment of success or cure, apnea hypopnea index (AHI), cephalometric changes, Epworth score, rapid eye movement sleep, body mass index, and various airway morphologic parameters.

Results: A total of 15 patients (13 men and 2 women) participated in the present study. The surgical success and cure rate was 73.33% and 40.00%, respectively. Statistically significant improvements were found in the airway total volume, minimal cross-sectional area, anteroposterior and lateral dimensions, airway index, airway length, posterior airway space morphology, AHI, and Epworth sleepiness score.

Conclusions: MMA is a highly successful surgical treatment of OSA that improves airway morphology and sleep quality. MMA results in a shorter and broader airway and associated improvements in the AHI.

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Obstructive sleep apnea (OSA) is a well-recognized, but underdiagnosed, disease entity, affecting an increasing segment of the population.[1-3] Undoubtedly, the reference standard for the management of OSA is continuous positive airway pressure (CPAP), which pneumatically stents the airway open during sleep to prevent obstruction. However, compliance has been low, because CPAP is poorly tolerated,[4-6] leading patients to seek surgical alternatives. MMA is a well-accepted surgical alternative for the treatment of OSA, with high surgical success,[7-18] stability,[18] and low complication rates.[9,19]

The treatment outcomes of MMA have demonstrated improvements in sleep quality equivalent to patients using CPAP therapy.[20,21] MMA positively changes the airway morphology, reversing the long,[22-26] narrow,[22,23,27] and circular[24,28-30] airways typically seen in patients with OSA. The resultant

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increases in the airway dimensions and reduction in pharyngeal collapsibility occur through advancement of the bony insertion sites for the airway musculature.[21,31]

Cephalometric imaging has been commonly used to assess the anatomy of the facial skeleton and upper airway. However, it is limited in its representation of 3-dimensional (3D) structures. Cone-beam computed tomography (CBCT) is a reliable diagnostic imaging system[32] that provides 3D representation of the head and neck at lower doses of radiation than traditional CT scans.[33,34] Numerous studies have used CBCT to provide more accurate 3D imaging of the airway morphologic changes associated with various surgical interventions.[22-25,27,35-39]

The purpose of the present study was to evaluate the 2-dimensional and 3D morphologic airway changes associated with bimaxillary advancement in patients with OSA. We hypothesized that the hard tissue advancements of MMA would strongly correlate with improvements in the various airway soft tissue morphologic parameters (eg, airway volume [AV], posterior airway space [PAS], airway shape [lateral/anteroposterior (LAT/AP) ratio], and airway index [AI]). The specific aims of the present study were to *1)* evaluate the relationship between hard tissue advancement and airway soft tissue changes and *2)* correlate the airway soft tissue morphologic parameters to the changes in OSA severity.

Materials and Methods

The Ethics Review Board of the Ottawa Hospital Research Institute approved the present study.

STUDY DESIGN AND SAMPLE

To address the research purpose, we designed and implemented a retrospective cohort study that included patients who had undergone MMA surgery for treatment of OSA from May 2010 to February 2014. The inclusion criteria were a diagnosis of OSA from the findings on an overnight laboratory polysomnogram; obstruction site in the oropharynx using the Mallampati classification, lateral cephalographic findings, and fiberoptic nasopharyngoscopic findings; body mass index (BMI) less than 40 kg/m^2; age 18 to 65 years; health sufficient to undergo MMA surgery; and intolerance to CPAP after a minimum 3-month trial. Patients were excluded if their BMI was greater than 40 kg/m^2, they were insufficiently healthy to tolerate MMA, or the site of obstruction had been isolated to the nasopharynx or hypopharynx.

SURGERY

All patients underwent a standard Le Fort I osteotomy and bilateral sagittal split osteotomy with rigid internal fixation. The treatment of 10 patients included counterclockwise rotation of the occlusal plane, and 2 patients underwent cosmetic genioplasty, not involving the genial tubercles. All procedures were performed by the same surgeon (K.J.B.).

DATA COLLECTION

Each patient underwent lateral cephalometric radiography and CBCT (Planmeca Promax 3D Mid, Helsinki, Finland) before and after surgery. All images were obtained in natural head position, and the patients were asked to avoid swallowing during the scanning process. Postoperative CBCT and lateral cephalograms were obtained 2 to 49 months postoperatively. Polysomnograms were obtained 1 to 29 months after treatment.

Imaging was imported into Dolphin 3D imaging software, version 11.7 (Dolphin Imaging and Management Solutions, Chatsworth, CA), for analysis. The CBCT scans, in digital imaging and communications in medicine format, were uploaded for analysis. Volumetric measurements were taken relative to the natural head position in the sagittal plane containing the incisive canal and included the nasopharyngeal and oropharyngeal regions. The borders of the airway were defined as the posterior nasal spine superiorly, the tip of the epiglottis inferiorly,[36] the lateral and posterior pharyngeal walls, and the posterior border of the tongue. The nasopharynx and oropharynx were measured as the volume from the posterior nasal spine to the tip of the uvula and the tip of the uvula to the tip of the epiglottis, respectively.[23,24] Linear surgical advancement of the incisal edges was measured using the Erickson model platform (Great Lakes Orthodontics, Tonawanda, NY). The surgical changes of the posterior airway space and occlusal plane rotation were measured using Cephalometric for Orthognathic Surgery analysis.

STUDY VARIABLES

The independent variables included the time of treatment and magnitude of skeletal movement. The dependent variables included the total AV, airway length (AL), AI (AV/AL ratio),[40] PAS, volume of the oropharynx and nasopharynx, narrowest airway cross-sectional area as measured in the axial plane (minCSA) of each pharyngeal compartment; LAT and AP dimensions of the minCSA, LAT/AP ratio of the minCSA, apnea hypopnea index (AHI), Epworth sleepiness score (ESS), BMI, and percentage of sleep spent in rapid eye movement (%REM).

STATISTICAL ANALYSIS

The data were analyzed using Microsoft Excel, version 14.4.3 (Microsoft Corp, Redmond, WA). The Student paired *t* test was used to evaluate the effect of surgical intervention on the AHI, ESS, %REM, AV, AL, AI, PAS, nasopharyngeal and oropharyngeal volumes, minCSA, LAT and AP dimensions, and LAT/AP ratio. Surgical success was defined as a reduction in the AHI by 50% or more and a postoperative AHI of less than 20. Surgical cure was defined as a postoperative AHI of less than 5. A P value < .05 was considered significant. Simple linear regression analysis was used to evaluate the relationships between the airway dimensions and parameters of sleep quality.

Results

The demographic patient data are summarized in Table 1. A total of 15 consecutive patients (13 men and 2 women) were included in the present study, with an age range of 19 to 61 years. Of the 15 patients, 7 had undergone previous airway surgery. The BMI was 30.33 ± 4.18 kg/m^2 preoperatively and 30.05 ± 3.78 kg/m^2 postoperatively (P > .05). The linear maxillary advancement and linear mandibular advancement was 8.07 ± 2.60 mm and 10.8 ± 2.34 mm, respectively (Fig 1). Ten patients underwent counterclockwise rotation of the occlusal plane (mean −6.14° ± 3.67°), with a negative change denoting rotation in the counterclockwise direction. Five patients underwent neutral or positive occlusal plane rotation (mean 0.82° ± 1.06°). The AHI had decreased from 45.5 ± 27.6 events/hr (range 10.5 to 83.7) preoperatively to 7.7 ± 6.0 events/hr (range 0 to 20) postoperatively (P < .001). The surgical success and cure rate was 73.33% and 40.00%, respectively.

The changes in sleep quality are summarized in Table 2. After surgery, the AHI had decreased by 83.1% (P < .001) and the ESS had decreased by 53.3% (P < .001). The %REM sleep had improved by 68.0%, approaching statistical significance (P = .051).

The airway morphologic changes are summarized in Table 3. The total AV had increased by 80.43% (P < .001) and the minCSA by 212.59% (P < .001). The AI had increased significantly by 109.13% (P < .001), the AL had decreased by 12.63% (P < .001), and the PAS had increased by 106.28% (P < .001). A significant increase in both the nasopharyngeal volume by 76.05% (P < .01) and the oropharynx volume by 89.15% (P < .05) occurred postoperatively. The minCSA had increased by 160.21% (P < .001) and 118.54% (P < .005) in the nasopharynx and oropharynx, respectively. The LAT dimensions had increased in the nasopharynx by 42.27% (P < .001) and by 43.26% (P < .001) in the oropharynx, and the AP dimensions had increased more in the nasopharynx (125.73%, P < .001) than in the oropharynx (47.94%, P < .005).

The LAT/AP ratio had decreased significantly in the nasopharynx postoperatively by 41.29% (P < .05); however, a decrease of 6.98% in the LAT/AP ratio of the

Table 1. PATIENT DEMOGRAPHIC DATA

Pt. No.	Age (yr)	Gender	Previous Airway Surgery	BMI (Kg/m^2) Preoperatively	BMI (Kg/m^2) Postoperatively	AHI Preoperatively	AHI Postoperatively	Concomitant Procedure
1	37	Male	T, A	27.6	26.5	76.8	6	None
2	51	Male	None	33.9	32.8	24.6	5	GP
3	30	Male	None	23	22.43	78	0	None
4	28	Male	MMA, GP	27.2	26.7	17.3	11.6	None
5	35	Male	None	33	34.4	12	8	None
6	44	Female	T	30.8	25.7	30.5	2.1	None
7	41	Male	None	35.1	29.9	21.3	16.5	None
8	44	Male	None	33.1	36.0	83.7	2.4	None
9	37	Male	LAUP	30.4	34.6	70.6	2.8	None
10	50	Male	UPPP	28.3	26.5	49.8	20	None
11	49	Female	None	26.6	26.9	29	13.8	None
12	50	Male	None	38.1	31.7	70.5	11.6	GP
13	60	Male	UPPP, SP	27.8	28.6	31	10	None
14	61	Male	T	30.7	30.1	10.5	2.2	None
15	19	Male	UPPP, T	34.4	32.9	77.47	3.7	None
Mean	42.4	—	—	30.3	30.0	45.5	7.7	—

Abbreviations: A, adenoidectomy; AHI, apnea hypopnea index; BMI, body mass index; GP genioplasty; LAUP, laser-assisted uvulopalatoplasty; MMA, maxillomandibular advancement; UPPP, uvulopalatopharyngoplasty; SP, septoplasty; T, tonsillectomy.

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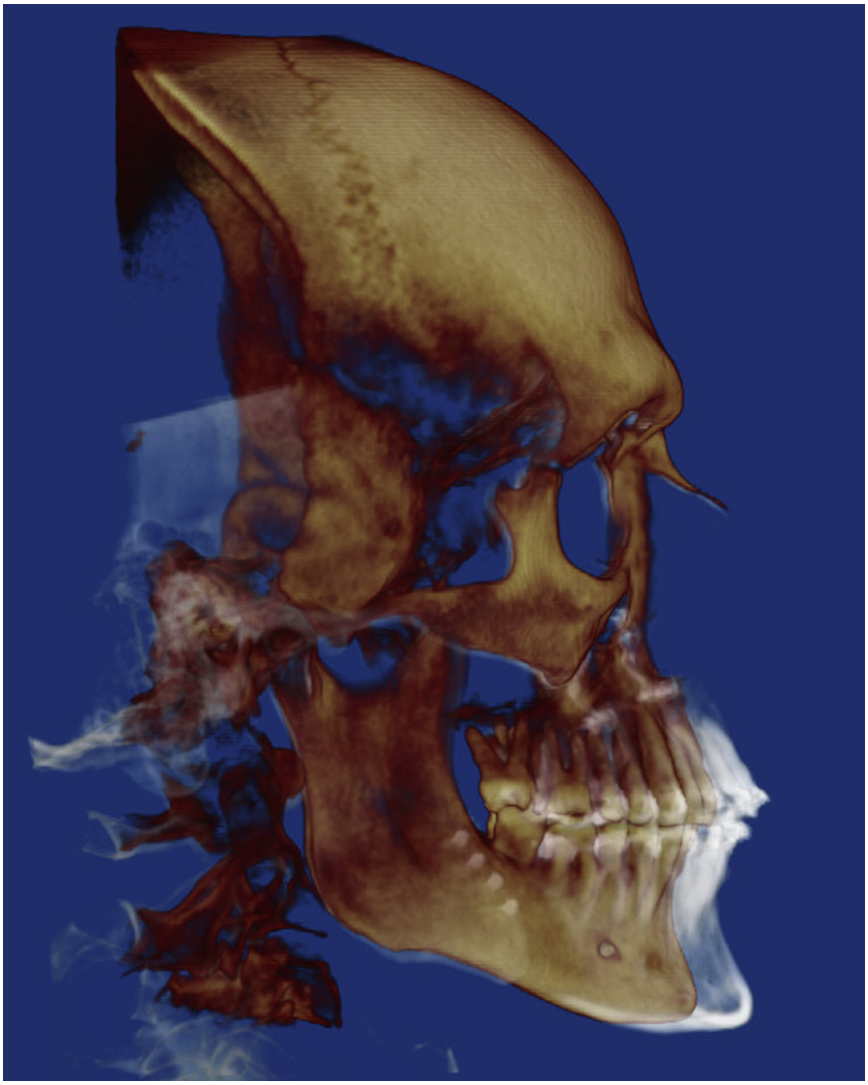

FIGURE 1. Superimposition of the pre- and postoperative cone-beam computed tomography scans. The final position (*white*) represents the surgical advancement of the maxillomandibular complex.

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oropharynx was not statistically significant ($P = .450$). The location of the greatest airway narrowing was predominantly in the nasopharynx; therefore, the LAT/AP ratio of the airway had also decreased significantly in the postoperative period (−42.33%; $P < .05$). The total AV correlated significantly with an increase in the PAS ($r = .650$, $P < .001$), but no statistically significant correlation was present between the change in the PAS and maxillary or mandibular advancement. Maxillary advancement correlated significantly with the

Table 2. PRE- AND POSTOPERATIVE SLEEP QUALITY

Sleep Parameter	Preoperative	Postoperative	Operative Changes (%)	*P* Value
AHI	45.54 ± 27.60	7.71 ± 5.98	−83.06	< .001
ESS	13.15 ± 4.14	6.14 ± 3.13	−53.30	< .001
%REM	10.52 ± 5.97	17.68 ± 6.75	68.00	.051

Data presented as mean ± standard deviation.

Abbreviations: AHI, apnea hypopnea index; ESS, Epworth sleepiness score; %REM, percentage of sleep in rapid eye movement.

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Table 3. PRE- AND POSTOPERATIVE AIRWAY MORPHOLOGY PARAMETERS

Parameter	Preoperative	Postoperative	Operative Changes (%)	*P* Value
Total airway				
AV (mm^3)	9,720.18 ± 3,650.40	17,538.32 ± 7,195.46	80.43	< .001
minCSA (mm^2)	79.09 ± 51.98	247.24 ± 100.45	212.59	< .001
LAT (mm)	15.93 ± 5.73	23.89 ± 4.90	49.98	< .001
AP (mm)	4.37 ± 2.24	10.71 ± 3.55	145.07	< .001
LAT/AP ratio	4.38 ± 2.67	2.53 ± 1.33	−42.33	.039
AI (cm^3/mm)	0.170 ± 0.053	0.356 ± 0.129	109.13	< .001
AL (mm)	57.03 ± 6.25	49.83 ± 7.94	−12.63	< .001
PAS (mm)	6.48 ± 2.35	13.37 ± 3.03	106.28	< .001
Nasopharynx				
VOL (mm^3)	6,470.45 ± 2,891.69	11,391.53 ± 6,198.09	76.05	.008
minCSA (mm^2)	96.75 ± 75.99	251.76 ± 103.13	160.21	< .001
LAT (mm)	16.98 ± 6.87	24.15 ± 4.86	42.27	< .001
AP (mm)	4.72 ± 2.71	10.66 ± 3.62	125.73	< .001
LAT/AP ratio	4.37 ± 2.67	2.57 ± 1.33	−41.29	.043
Oropharynx				
VOL (mm^3)	3,249.73 ± 1,256.08	6,146.79 ± 4,375.95	89.15	.015
minCSA (mm^2)	147.25 ± 74.26	321.79 ± 147.74	118.54	.002
LAT (mm)	19.51 ± 5.71	27.95 ± 7.90	43.26	< .001
AP (mm)	9.15 ± 2.78	13.53 ± 3.71	47.94	.001
LAT/AP ratio	2.30 ± 0.90	2.14 ± 0.56	−6.98	.450

Data presented as mean ± standard deviation.

Abbreviations: AI, airway index; AL, airway length; AP, anteroposterior dimension at minCSA; AV, total airway volume; LAT, lateral dimension at minCSA; minCSA, minimum axial cross-sectional area; PAS, posterior airway space; VOL, volume.

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reduction in AHI ($r = -0.771$, $P < .001$), but mandibular advancement did not ($P = .564$).

The relationships of the airway parameters to the AHI are summarized in Table 4. The reduction in the AHI correlated significantly with a gain in the PAS ($r = -0.542$, $P < .005$), minCSA ($r = -0.399$, $P > .05$), and AI ($r = -0.394$, $P > .05$). The AHI correlated directly with the AL ($r = 0.471$, $P < .01$), and no significant relationship between the AHI and AV was present ($P = .152$).

Table 4. CORRELATIONS TO AHI

Parameter	*r*	*P* Value
PAS	−0.542	.002
Airway minCSA	−0.399	.044
AV	−0.289	.152
AL	0.471	.009
AI	−0.394	.047

Abbreviations: AHI, apnea hypopnea index; AI, airway index; AL, airway length; AV, airway volume; minCSA, minimal axial airway cross-sectional area; PAS, posterior airway space; *r*, correlation coefficient.

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Discussion

The present study investigated the linear and volumetric morphologic changes that occur in the pharyngeal airway after treatment of OSA with MMA. We hypothesized that the hard tissue advancements of MMA would beneficially improve the various airway soft tissue morphologic parameters (ie, AV, PAS, LAT/AP ratio, and AI), quantifying the relationship between the hard tissue advancement and airway soft tissue changes and the resultant effect on OSA severity. In the present study, the surgical success and cure rate was 73.33% and 40.00%, respectively. Significant changes in all linear and volumetric measurements were found postoperatively, except for the LAT/AP ratio of the oropharynx. The improvement in the AHI ($P < .001$) and ESS ($P < .001$) were statistically significant, and the improvement in the %REM sleep approached significance.

MMA is a well-established surgical treatment of patients with OSA. Through the advancement of the bony insertion sites of the pharyngeal airway musculature, MMA increases the total AV, tightens the lateral pharyngeal walls,[21,31] and changes the shape of the airway from circular to oblong,[24,28-30] resulting in an airway that is less prone to collapse. After MMA, the number of obstructive events and concomitant sleep disruptions can be expected to decrease, improving the patient's overall sleep quality and treating the negative physiologic effects of sleep disordered breathing.

A reduction in the AHI of 83% was found in the present study, consistent with the review by Prinsell[41] of the published data, which showed an 88% reduction among the evaluated studies. The surgical success of MMA for the treatment of OSA has a reported range of 65 to 100% when using the single success criterion of a postoperative AHI of less than 20.[12] Using the more rigorous definition[9,18,19,23,42] of a reduction in AHI of 50% or more in addition to a postoperative AHI of less than 20, the surgical success of the present study was 73%, consistent with the success rate in previous studies.[9] However, these definitions could still leave the patient with moderate OSA. Eishaug et al[43] stated that the goal of a surgical cure should be more widely expected and reported in published studies. The present study showed a surgical cure rate of 40%, similar to the 43% reported by 2 recent meta-analyses.[9,43]

Significant changes in the sleep parameters occurred in the present study. Consistent with previous research,[9,20] the %REM improved from 11 to 18%, approaching clinically normal values.[44] Similarly, the ESS decreased significantly to a clinically normal value of 6.14,[45] in agreement with the findings of previous studies.[9,18]

In the present study, CBCT imaging was used to quantify the linear and volumetric changes of the pharyngeal airway in patients with OSA before and after MMA. 3D imaging has allowed for new insight into the airway morphologic changes associated with surgical interventions. A limited number of studies evaluating the 3D morphologic changes of the airway in patients with OSA treated with MMA have been published.[22-24,35,36] Volumetric increases in the pharyngeal airway after MMA in patients with and without OSA have been reported.[22-24,27,35,36] The AV in the present study increased by 80.43%, more than the 45 to 56% increases found in previous MMA studies[24,27] and the 32% seen with mandibular advancement alone.[37] Differences in the volumetric increases among the studies might have resulted from the different parameters used to delineate the airway boundaries, variations in the magnitude of surgical advancement and rotation of the occlusal plane, the use of helical[24] versus CBCT scanners, and/or differences in the BMI of the patient populations. Despite significant airway volumetric increases in the present study, the AV was not associated with improvement in the AHI.

The minCSA in the present study improved significantly in both pharyngeal compartments, improving from 79.09 mm^2 preoperatively to 247.24 mm^2 postoperatively for the complete airway length (Fig 2). Previous studies[22,46,47] found the minCSA values in patients with OSA to be 38.88 to 60.5 mm^2. The minCSA of patients with OSA has been found to be narrower than that of those who snore[48,49] and those without OSA.[50] Comparatively, other studies have also reported significant increases in the minCSA after MMA surgery[22,23,27] and mandibular advancement surgery,[37] with narrowing reported with mandibular setback surgery.[38,39] The variation in the preoperative minCSA values among studies might have resulted from differences in OSA severity[22,46,48,49,51] or craniofacial morphology[52,53] in the patient populations or differences in the respiratory phase[54,55] and head position[56] at the point of image capture. Despite these variations, it can be concluded that patients with OSA present with a narrowed minCSA relative to healthy individuals and the minCSA will improve with MMA. In the present study, the minCSA showed a significant inverse correlation to the AHI. Vos et al[46] reported similar findings, and Li et al[51] reported an inverse correlation between the minCSA and RDI. Furthermore, an increased minCSA after MMA has been shown to improve the fluid dynamics of respiration.[57,58]

Increased airway length is associated with an increased incidence and severity of OSA.[50,59-61] Several studies have reported a decrease in airway length after MMA.[22-26] Similarly, the airway length decreased postoperatively in the present study and was associated with an improvement in the AHI. Significant increases in minCSA and airway volume were also found in the present study. Collectively, the airway became shorter, wider, and more voluminous, corresponding to a significant increase in the airway index (Fig 3). Similar airway morphologic changes have been reported previously.[22-24] Using the principles of Poiseuille's law to explain OSA severity, several investigators[22,24,46,50,60] have related an increased airway volume and width and decreased length to a reduction in the airway resistance and obstruction. Sittitavornwong and Waite[57] reported improved airflow with increased minCSA and airway volume. Schendel et al[58] found that increased minCSA was associated with decreased airflow turbulence; however, only 1 patient was included in their study.

As previously established by Riley et al,[62] a PAS less than 11 mm was predictive of OSA. In the present study, the PAS increased significantly from less than 11 mm preoperatively to greater than 11 mm postoperatively. In addition to a direct association with airway volume, the PAS was inversely related to the AHI. Similar findings were also reported in a meta-analysis by Holty and Guilleminault.[9] However, other studies[31,63,64] have observed improvements in OSA severity with postoperative PAS values of less than 11 mm. Although increases in the PAS were associated with an increase in volume, no significant

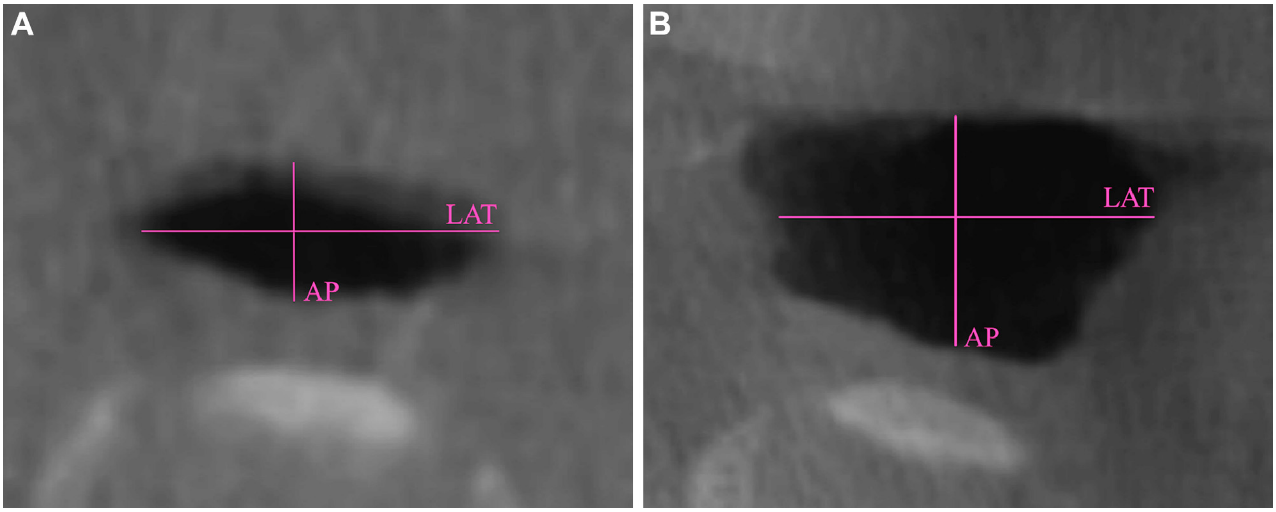

FIGURE 2. *A*, Preoperative narrowest airway cross-sectional area and *B*, postoperative narrowest airway cross-sectional area. Significant increases in the lateral and anteroposterior dimensions occurred after maxillomandibular advancement.

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relationship was observed between the PAS and the magnitude of maxillary or mandibular advancement in the present study. In mandibular advancement studies, the change in the PAS owing to surgical advancement has not been found to be reliable.[65] The absence of an association with surgical advancement, combined with the lack of a consistent definition of PAS among researchers,[9,16,20,63,65-67] might limit the value of PAS in treatment planning and outcome prediction.

Similar increases in the LAT dimension of both pharyngeal airway compartments were found in the present study, although greater increases in both the AP dimension and volume occurred in the nasopharynx than in the oropharynx. In contrast, Zinser et al[24] found a greater oropharyngeal AP increase after MMA. The increased airway volume in the nasopharynx of the present study might have been the effect of increased soft palate tension[30,57] and of counterclockwise rotation of the occlusal plane.[25,67,68] The difference in the postoperative morphologic and volumetric changes between the nasopharynx and oropharynx might account for the relationship of the AHI to maxillary but not mandibular advancement, suggesting that the volumetric change of the nasopharynx might have a greater effect on AHI. Several studies have found similar correlations between maxillary, but not mandibular, advancement and a reduction in the AHI.[9,42]

The LAT/AP ratio of the airway has been suggested to influence airway collapsibility, with a laterally widened elliptical airway preferable for airflow.[24,28,29,50,69,70] The airway of snorers and healthy individuals was found to be more laterally oriented than that of those with OSA.[48,69] In contrast, Ogawa et al[47] noted that those with OSA had an airway that was more elliptical than that of the controls. Fairburn et al[30] found that MMA increased both the LAT and AP dimensions of the airway, finding greater increases in the LAT than the AP dimension of the retroglossal region. Zinser et al[24] also noted larger LAT than AP gains postoperatively. In the present study, the LAT/AP ratio of the nasopharynx had decreased significantly, indicating a greater relative AP than LAT increase. The oropharyngeal LAT/AP ratio remained approximately constant postoperatively, and the absolute values of the LAT and AP dimensions both increased, consistent with the findings from Abramson et al.[22]

The AI represents the relationship of 2 airway parameters associated with OSA.[22] An increase in the AI, corresponding to a greater volume and shorter airway, therefore, likely results in favorable reductions in airway resistance. The AI of the present study correlated inversely to the AHI, supporting the interpretation of Poiseuille's law to understand the relationship of airway resistance and obstruction. Schendel et al[40] studied 1,300 airways in patients without OSA to establish the age-based norms for comparison purposes. The present study represents the first report of AI evaluation in a population with OSA. The preoperative AI value of 0.174 in the present study was less than the 0.23 expected for the average aged individual without OSA.[40] In addition, the AI increased 109% with MMA, resulting in values typically associated with patients without OSA. However, additional research is necessary to establish AI values for specific groups according to age and gender with OSA, in order to evaluate the relevance and predictive value of the AI to OSA severity and magnitude of surgical advancement necessary to effect a cure.

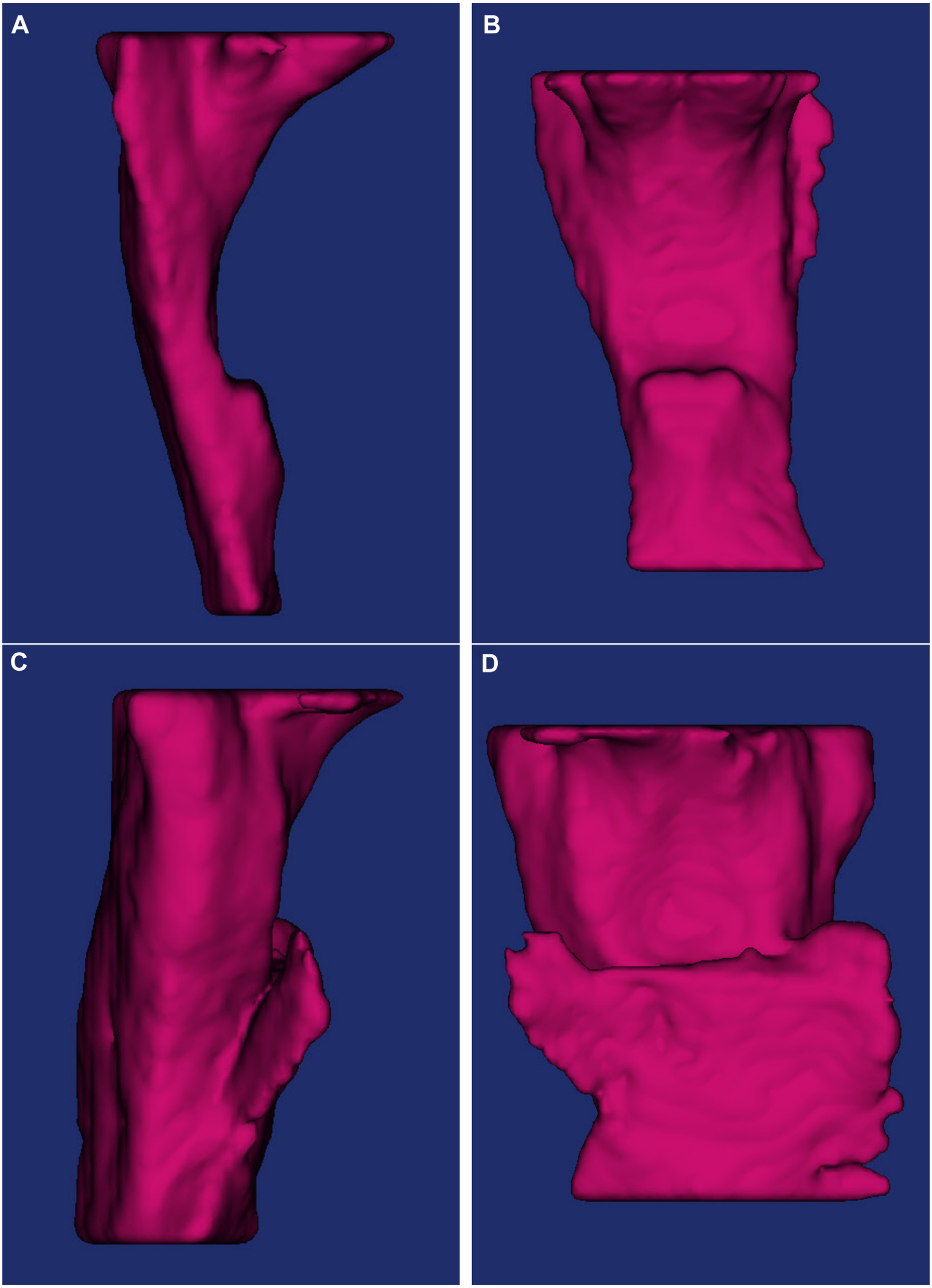

FIGURE 3. Preoperative views of the narrowed airway in the *A*, sagittal and coronal *B*, planes, and Postoperative views of the enlarged airways in the *C*, sagittal and *D*, coronal planes.

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Several limitations exist for the present study. A relatively small sample size, wide age distribution, and dissimilar gender distribution would limit one's ability to use these findings to predict the surgical outcomes according to patient age and gender. In addition, neither the CBCT scans nor overnight polysomnograms were obtained at uniform points postoperatively, introducing the potential that the timing of the imaging and polysomnographic investigations could yield differing results. The largest shortcoming is assuming that the static airway morphology in an awake, upright patient with normal muscle tone correlates to its dynamic counterpart in the supine position, during REM sleep. Current technical limitations in the ability to quantitatively assess the airway in its dynamic form during episodes of obstruction need to be overcome to allow for the most accurate assessment of airway morphology in patients with OSA.[71] Finally, we used a retrospective study design, which could have resulted in a selection bias.

In conclusion, MMA for the treatment of OSA is a highly successful surgical procedure, resulting in beneficial improvements across various airway morphologic and sleep parameters. Future evaluations using a more stringent study design, a larger sample size, dynamic imaging of the airway,[71] and standardization of the timing of the postoperative investigations is warranted to individualize the treatment of patients with OSA.

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