

Tongue and Lateral Upper Airway Movement with Mandibular Advancement

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Study Objectives: To characterize tongue and lateral upper airway movement and to image tongue deformation during mandibular advancement.

Design: Dynamic imaging study of a wide range of apnea hypopnea index (AHI), body mass index (BMI) subjects.

Setting: Not-for-profit research institute.

Participants: 30 subjects (aged 31-69 y, AHI 0-75 events/h, BMI 17-39 kg/m²).

Interventions: Subjects were imaged using dynamic tagged magnetic resonance imaging during mandibular advancement. Tissue displacements were quantified with the harmonic phase technique.

Measurements and Results: Mean mandibular advancement was 5.6 ± 1.8 mm (mean \pm standard deviation). This produced movement through a connection from the ramus of the mandible to the pharyngeal lateral walls in all subjects. In the sagittal plane, 3 patterns of posterior tongue deformation were seen with mandibular advancement—(A) en bloc anterior movement, (B) anterior movement of the oropharyngeal region, and (C) minimal anterior movement. Subjects with lower AHI were more likely to have en bloc movement ($P = 0.04$) than minimal movement. Antero-posterior elongation of the tongue increased with AHI ($R = 0.461$, $P = 0.01$). Mean anterior displacements of the posterior nasopharyngeal and oropharyngeal regions of the tongue were $20\% \pm 13\%$ and $31\% \pm 17\%$ of mandibular advancement. The posterior tongue compressed 1.1 ± 2.2 mm supero-inferiorly.

Conclusions: Mandibular advancement has two mechanisms of action which increase airway size. In subjects with low AHI, the entire tongue moves forward. Mandibular advancement also produces lateral airway expansion via a direct connection between the lateral walls and the ramus of the mandible.

Keywords: Obstructive sleep apnea, mandibular advancement splint, pterygomandibular raphe, lateral walls,

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INTRODUCTION

While it is well known that chin lift increases airway patency,¹ the mechanism by which a mandibular advancement splint (MAS) improves obstructive sleep apnea (OSA) is poorly understood. An MAS fixes the mandible in an anterior position with the aim of decreasing airway collapsibility but is effective in only ~50% of patients.² Clinical variables which are favorable for MAS treatment include lower apnea hypopnea index (AHI), body mass index (BMI), female gender, primary oropharyngeal site of collapse, and some cephalometric and polysomnographic variations.²⁻⁵ Amount of mandibular advancement achieved also is related to treatment success.²

Mandibular advancement increases the lateral dimensions of the nasopharynx.⁶⁻¹⁰ Proposed mechanisms for this action include: mechanical effects via the genioglossus⁶ or palatine arches^{6,11}; improvement in the nasopharyngeal airway due to anterior forward movement of the soft palate via its lateral connections^{6,8,12}; decreased extraluminal tissue pressure in the anterior and lateral walls of the airway¹³; and increased airway muscle activity.^{14,15} The mechanism is thought to be largely mechanical because mandibular advancement improves airway patency during paralysis,⁶ although MAS increases neuromuscular activation.¹⁵ Mandibular advancement changes airway

shape,^{6,8} but it is unclear why airway dimensions are improved in the lateral more than antero-posterior dimension in the nasopharynx.^{7,8,16} To our knowledge, the effect of mandibular advancement on the soft tissues surrounding the upper airway has not been dynamically imaged.

Spatial modulation of magnetization (SPAMM) is a tagged magnetic resonance imaging (tMRI) technique which superimposes a grid of “tag lines” on the tissue. The tissue magnetization is spatially modulated in the grid pattern prior to imaging, so these regions appear dark on subsequent images. Grid movement and deformation are measured from ultra-fast images taken after tagging. SPAMM has previously been used to measure the deformation of the tongue in young healthy individuals.¹⁷ Our aim was to quantify the movement of the tissues surrounding the airway during mandibular advancement to clarify the mechanism of action. Mechanical connections in the tongue and between upper airway structures, such as the mandible and the lateral walls of the nasopharynx were of particular interest. The hypothesis was that mandibular advancement would move the lateral walls of the nasopharyngeal airway and deform the tongue base.

METHODS

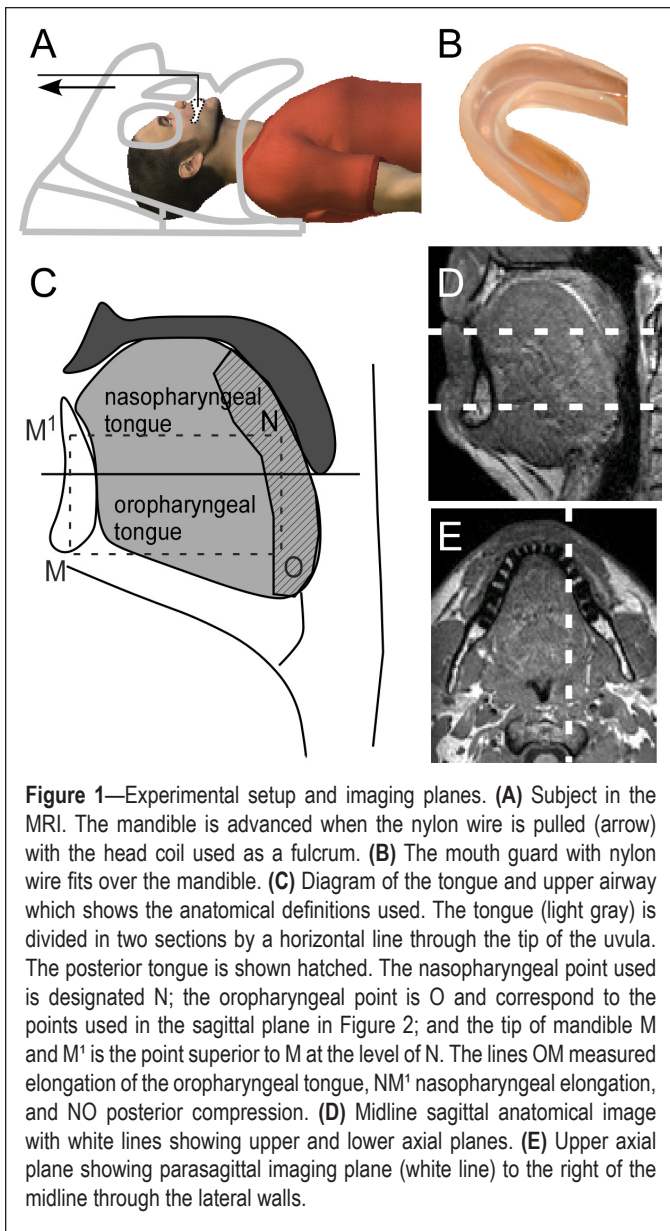
Thirty subjects (aged 31-69 years) with no contraindications for MRI were recruited through the Prince of Wales Hospital Sleep Clinics. Two subjects had technically inadequate axial images excluded from analysis. Subjects covered a wide spectrum from normal to severe OSA (apnea-hypopnea index [AHI] range 0-75 events/h sleep, 3 normal subjects) and BMI (range 17-39 kg/m²). Some subjects not usually considered for MAS were included to investigate the mechanics of the tongue

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with increasing BMI. No patient had received prior treatment for OSA. Subjects with severe chronic illness, medication that could affect upper airway muscle, or previous upper airway surgery were excluded, but minor orthodontic work was allowed. The study was approved by the University of New South Wales and Prince of Wales Hospital Human Research Ethics Committees. Written informed consent was obtained, and the study conformed to the Declaration of Helsinki.

Polysomnography

Normal subjects were either recruited through the sleep laboratory and underwent standard clinical polysomnography or were studied at home using an Embletta X50 (Medcare, Iceland) with one EEG lead, nasal airflow, pulse oximetry, position, and thoracic and abdominal bands. Home studies were scored by a sleep physician. In OSA subjects, in-laboratory polysomnography was performed using standard techniques, including electroencephalography (EEG), electrooculography, electrocardiogram, submental electromyogram (EMG), anterior tibialis EMG, nasal airflow measured with pressure transducer, pulse

oximetry, thoracic and abdominal respiratory effort, and position. Sleep was scored in 30-s epochs by an experienced technician. All studies were scored according to AASM alternative criteria,¹⁸ with hypopnea defined as 50% reduction in airflow accompanied by desaturation of 3% or an arousal.

Experimental Protocol

Subjects were positioned within the MRI head-neck coil with the Frankfort plane vertical and padding to minimize head movement. Subjects were instructed to hold their breath at a comfortable end-expiratory level while images were acquired (2 sec). The mandible was manually advanced with an oral device (Figure 1B, Elastoplast Sport, # 30320, adult or youth size) fitted over the bottom teeth, by pulling a nylon wire anteriorly (Figure 1A). Several practice runs were performed until reproducible movement was obtained with the subject's jaw muscles relaxed. The mandible was advanced until resistance was felt. Images were taken in the midline sagittal plane and 2 axial planes (Figure 1D). A parasagittal plane (10 mm lateral to the left lateral wall of the nasopharynx) was added if time allowed ($n = 14$, Figure 1E). The upper axial plane was defined as the narrowest part of the nasopharynx on the sagittal scout image. A lower axial plane through the base of the genioglossus muscle was also imaged. Three to five repeats were performed in each plane.

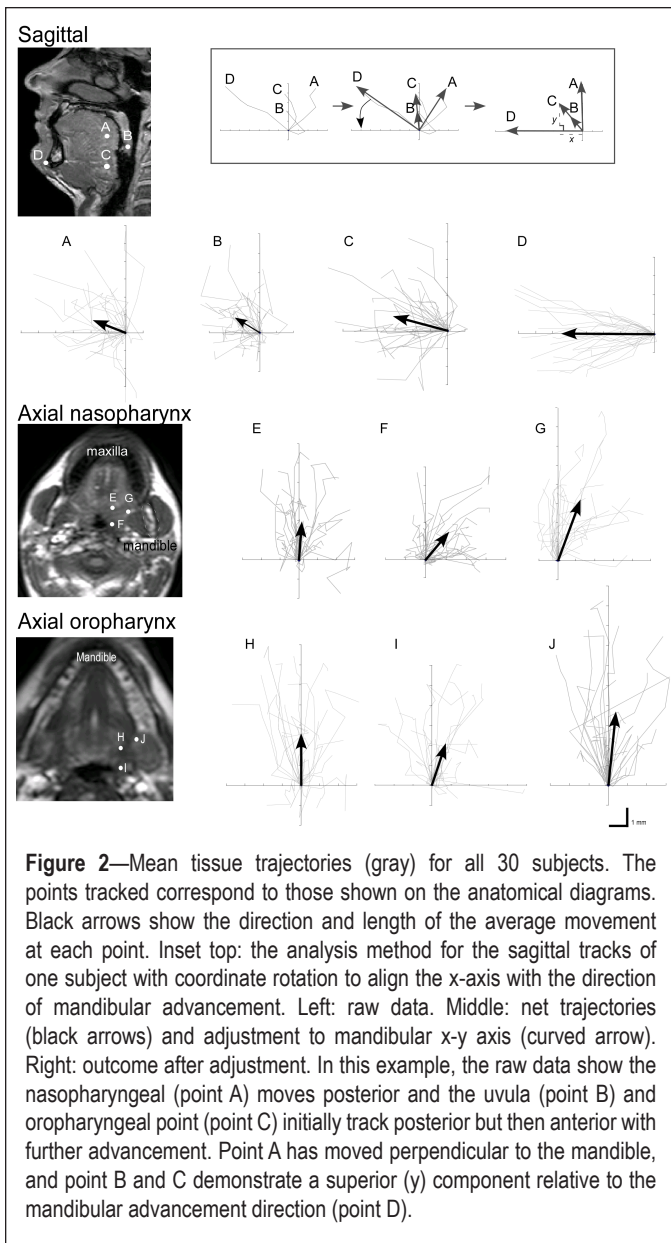
tMRI Technique

An available SPAMM sequence on a 3T MRI scanner was used (Philips, Achieva 3T, Best, The Netherlands). After grid production, 8 images were taken 250 ms apart during mandibular advancement. The imaging parameters were: flip angle 90 deg; spin echo repetition time 400 ms; echo time 16 ms; FOV = 178, 10, 200; 256×256 matrix and tag spacing 8.6 mm, slice thickness = 10 mm. Detailed anatomical images (T1T2, 3D mode, FOV = $256 \times 256 \times 130$, 256×256 matrix, 130 slices, slice thickness = 1 mm) were taken at the end of the experiment. The hyoid mandibular plane distance (H-MP) and mandibular plane angle (MPA) were measured using bony landmarks in 3 dimensions.¹⁰

Analysis

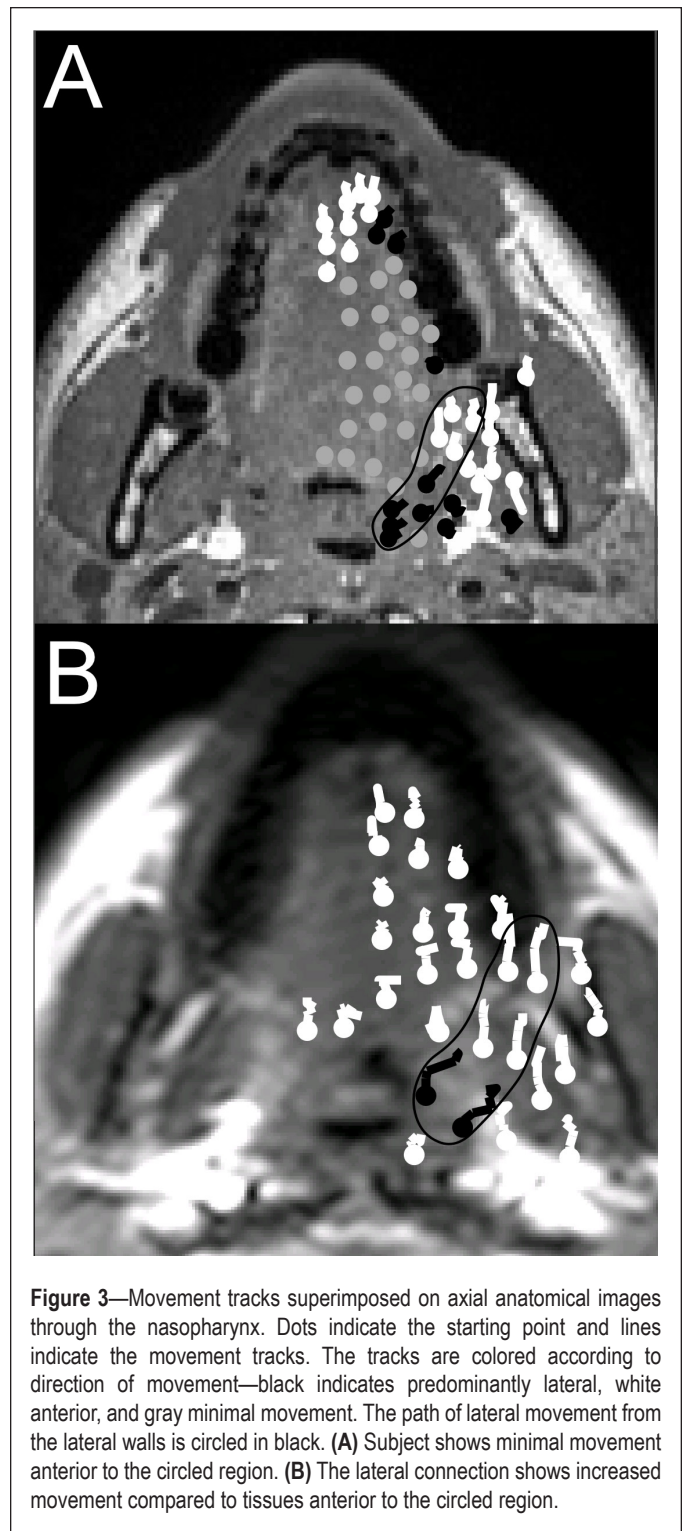
Analysis of image sequences was performed using the harmonic phase (HARP) method¹⁹ implemented in Matlab (The MathWorks Inc, Natick, MA, USA). HARP allows tissue deformation to be computed at sub-pixel resolution, from the changes in spatial frequencies in the tMRI data.^{19,20} Image sequences with mouth opening > 1 mm, head movement > 1 mm, or mandibular advancement < 4 mm were excluded. When subjects had more than one suitable image sequence in that plane, all were analyzed and the results averaged.

Points of interest (Figure 2, anatomical images) were selected on the undeformed grid images and movement of the points tracked through 8 images. The points were defined as follows: (A) 1 cm anterior to the posterior border of the tongue at the level of the narrowest nasopharynx in the sagittal plane, (B) tip of the uvula, (C) midpoint of the oropharynx directly inferior to point A, (D) the mandible, (E and H) directly anterior to the left lateral wall (points F and I), 1 cm anterior to the anterior airway wall of the nasopharynx and oropharynx, respectively, (F and I) the left lateral wall of the nasopharynx and oropharynx, and



(G and J) approximately two-thirds along a tissue plane from the left lateral wall to the mandible. Points surrounding these points were used to confirm that the tracks were representative of the movement. The axial planes were also examined for movement of the lateral walls using tracks at regular intervals overlaid on a matching anatomical scan (Figure 3).

In the sagittal plane, the tracks were mapped in each subject in the image x-y coordinate system, then rotated so that the x-axis lay along the direction of mandibular motion (Figure 2, inset). For analysis, the components of the movement were expressed as a percentage of the movement of the mandible. Angle of movement was measured with reference to the positive x axis. In the upper axial plane, where the mandible motion was not in the imaging plane, the displacements are expressed as a percentage of the mandibular displacement in matching sagittal scans. In the sagittal plane, the tongue was divided into regions to describe where deformation occurred (Figure 1C). The nasopharyngeal region was the portion of tongue superior to a horizontal line through the tip of the uvula and the oropharyngeal



region was below this line. The posterior tongue was defined as the 10-15 mm of muscle adjacent to the airway.

A sagittal mesh (Figure 4) was constructed for each subject using the image sequence with the largest mandibular advancement. The pattern of sagittal motion was classified according to movement of the posterior tongue in the oropharyngeal and nasopharyngeal region. These 3 groups were: (A) en bloc anterior movement of the posterior tongue in the nasopharyngeal and oropharyngeal regions > 2 mm, (B) anterior movement > 2 mm of the posterior tongue in the oropharyngeal region only, and (C) minimal anterior

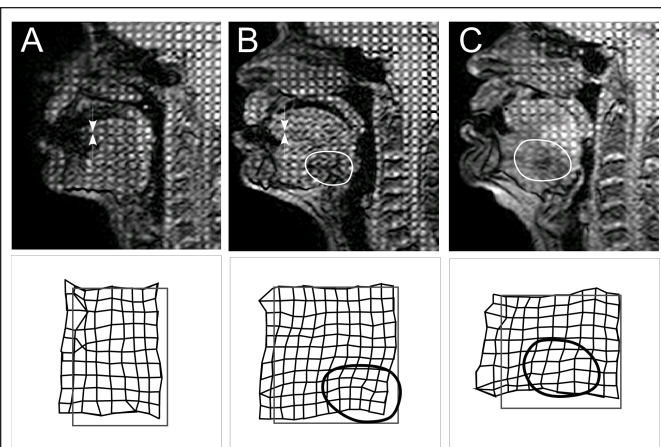


Figure 4—The three patterns of tongue displacement during mandibular advancement. MRI after 1.5 seconds of mandibular advancement for each pattern of movement is shown in the upper panels. The original grid spacing can be seen in adjacent brain tissue (top right), which has not moved. The lower panels are an enlarged view, showing the border of the original (undeformed) regular grid (gray rectangle) with the deformation after 1.5 seconds superimposed in black. The original tags were 8.6 mm apart. **(A)** The posterior tongue moves anteriorly en bloc. **(B)** The tongue moves anteriorly in the oropharyngeal region only (the oval shows deformation of the tags on the MRI image). Images A and B show supero-inferior compression of the tongue (white arrows on the MRI image). **(C)** Minimal anterior movement in either region. The oval indicates a region of antero-posterior elongation.

Table 1—Subject characteristics, presented as mean \pm standard deviation (range)

Number	30 (28 axial)
Sex	23M, 7F
Age (years)	44 \pm 10 (31 – 69)
BMI (kg/m ²)	29 \pm 6 (17 – 39)
AHI (events/h)	29 \pm 20 (0 – 75)
MPA (°)	27 \pm 6 (15 – 42)
ESS (n/24)	7 \pm 5 (0 – 17)
Mandibular advancement (mm)	5.6 \pm 1.8 (4.0 – 8.5)

MPA, mandibular plane angle, ESS, Epworth Sleepiness Score.

movement of the posterior tongue with mandibular advancement (< 1 mm). Group assignment was confirmed by a blinded review of each video sequence by a second researcher. The area of the mesh pre and post deformation was measured. Antero-posterior elongation was defined as the difference in distance of each point above from the mandible pre- and post-advancement. Supero-inferior compression of the posterior tongue was defined as the distance between the nasopharyngeal and oropharyngeal points pre- and post-advancement (see Figure 1C).

SPSS (Version 18, Chicago, IL) was used for all statistical analysis. Alpha was set at 0.05. Data are presented as mean \pm standard deviation. All distributions were normal apart from the movement of the lateral upper airway, which became normal after logarithmic transformation. Paired Student's *t*-tests were performed to compare the movement of specific pairs of points. In the sagittal plane the nasopharyngeal point (Figure 2, point A)

Table 2—Movement of upper airway tissues during simulated mandibular advancement, expressed as a percentage of the amount of mandibular advancement

Sagittal imaging plane	Nasopharynx point A	Oropharynx point B	P value
Antero-posterior displacement (%)	20 \pm 13	31 \pm 17	0.003
Superior displacement (%)	32 \pm 27	29 \pm 19	0.468
Axial imaging plane	Anterior point E	Lateral point F	P value
Resultant displacement (%)	46 \pm 26	47 \pm 33	0.397
Angle of movement (degrees)	77 \pm 51	41 \pm 53	0.007

Results from statistical comparisons between the displacements using Student *t*-test are also shown. The angle of movement of the axial points is shown with reference to the positive x axis. Measurement was taken from the points shown in Figure 2.

was paired with the oropharyngeal point (Figure 2, point B). In the upper axial plane movement at the lateral airway point (Figure 2, point F) was compared to the point anterior to the lateral point (Figure 2, point E). Pearson correlations were performed to assess the relationship between movement and AHI and other variables, and one-way ANOVA was used when there were > 2 groups. A priori power calculation indicated a sample size of 26 subjects was required to find a large effect (effect size 0.8) between the different points measured with a power of 0.8. This was based on assumed mean of 1 \pm 0.5 mm movement of the nasopharyngeal point compared to 2.5 \pm 0.5 mm movement of the oropharyngeal point.

RESULTS

Subject characteristics are shown in Table 1. Movies of mandibular advancement in 3 subjects, exhibiting the 3 characteristic motion patterns, are available in the supplemental material. Figure 2 shows the movement tracks for all subjects at all points studied, with mean displacements shown as arrows. Table 2 compares the amount of movement of the different points in the sagittal and axial planes, and Table 3 shows the correlations between movement and AHI, BMI, and MPA.

Axial Imaging Planes

All 28 subjects had movement from the anterior of the ramus of the mandible to the lateral walls of the airway in the upper axial plane in the region of the pterygomandibular raphe. Movement did not always extend all the way from lateral mandible to the nasopharynx in the plane studied. This lateral connection moved in a different direction to tissues anterior to the connection during advancement (Figure 3). There was no difference in total movement anterior or lateral to the airway (Table 2, point E and point F), but the direction of movement of these 2 points was significantly different ($P = 0.007$). The parasagittal imaging plane showed < 1 mm supero-inferior out-of-plane movement in the upper axial plane at the lateral walls of the airway (Figure 2, point F).

Table 3—Pearson correlation coefficients (R) between movement and OSA severity, obesity, and mandibular plane angle.

	Nasopharynx point A	Oropharynx point C	Upper axial lateral wall point F	Elongation
AHI	0.063	-0.111	-0.070	0.461*
BMI	0.180	-0.332	-0.155	0.323
MPA	-0.241	0.235	-0.473	0.078

Elongation of the nasopharyngeal tongue was the only variable which was statistically significant (indicated by asterisk). * $P < 0.05$. Points correspond to the anatomical points in Figure 2. MPA, mandibular plane angle.

Sagittal Imaging Plane

Movement for a typical subject in the sagittal plane and the coordinate system rotation used to align mandibular advancement with the x axis are shown in the inset of Figure 2. With mandibular advancement this subject had posterior movement of the nasopharyngeal (point A) and oropharyngeal points (C) in the antero-posterior plane. The nasopharyngeal point (A) moved almost perpendicularly to the direction of mandibular advancement (D). Overall, there was greater displacement in the oropharyngeal region ($31\% \pm 17\%$ of mandibular advancement) compared to the nasopharyngeal region ($20\% \pm 13\%$, Student *t*-test, $P = 0.003$). The superior component of movement of the nasopharyngeal point of 1.3 ± 2.0 mm ($32\% \pm 27\%$ of mandibular advancement superior component) and oropharyngeal point of 1.8 ± 1.7 mm ($29\% \pm 19\%$) were not significantly different (Student *t*-test, $P = 0.468$).

Tongue Deformation in the Sagittal Plane

On average the oropharyngeal tongue elongated antero-posteriorly by 2.5 ± 2.2 mm and the nasopharyngeal tongue 3.7 ± 1.7 mm. There was compression supero-inferiorly of 1.1 ± 2.2 mm. The posterior tongue compressed supero-inferiorly in 21/30 (70%) subjects. There were no cases where the oropharyngeal points and nasopharyngeal points moved in opposite directions during mandibular advancement. The mean mesh area pre-deformation ($1,974 \pm 736$ mm²) and post-deformation ($1,940 \pm 734$ mm²) were not significantly different ($P = 0.081$). Table 3 shows the correlations between antero-posterior elongation and the variables measured. AHI continued to show significant correlation with antero-posterior elongation in the nasopharyngeal region ($R = 0.461$, $P = 0.010$) after adjustment for BMI ($R = 0.389$, $P = 0.037$). Elongation was not related to BMI, despite a trend ($R = 0.323$, $P = 0.082$). Figure 4 shows the patterns of deformation and displacement of the tongue in the sagittal plane. In 10/30 (33%) subjects, the tongue elongated with mandibular advancement, but both the oropharyngeal and nasopharyngeal posterior tongue showed some anterior displacement (Figure 4, pattern A). In 8/30 (27%) the oropharyngeal tongue only showed anterior displacement (pattern B) and in 12/30 (40%) the tongue elongated antero-posteriorly with minimal displacement of the posterior oropharyngeal or nasopharyngeal tongue (pattern C). Pattern A was associated with a lower mean AHI (16 ± 16 events/h) compared to Pattern C (mean AHI = 39 ± 19 events/h, $P = 0.04$; Figure 5),

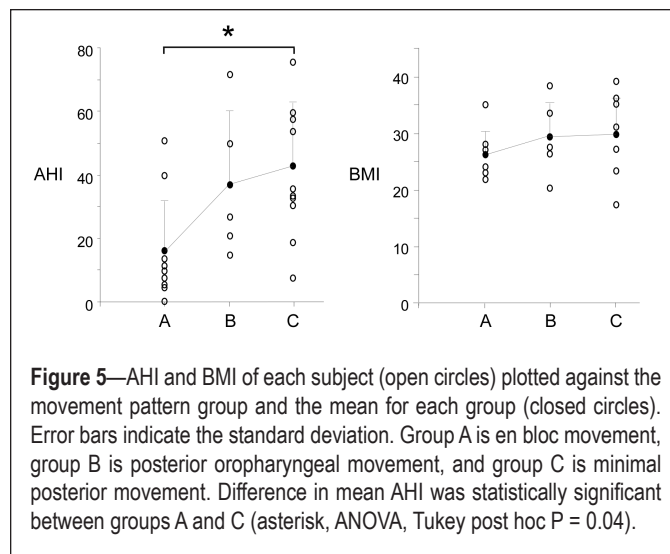


Figure 5—AHI and BMI of each subject (open circles) plotted against the movement pattern group and the mean for each group (closed circles). Error bars indicate the standard deviation. Group A is en bloc movement, group B is posterior oropharyngeal movement, and group C is minimal posterior movement. Difference in mean AHI was statistically significant between groups A and C (asterisk, ANOVA, Tukey post hoc $P = 0.04$).

DISCUSSION

This study is the first to define the movement and deformation of the soft tissues surrounding the upper airway during mandibular advancement. The study was conducted during wakefulness. There are three main findings. First, lateral wall tissues moved laterally with mandibular advancement via a connection from the lateral walls of the nasopharynx to the lateral mandible. Anatomically, the connection appeared to correspond to the region of the pterygomandibular raphe (see Figure 6). Second, the majority of subjects showed antero-posterior elongation of the tongue and rostro-caudal compression in the posterior tongue during mandibular advancement. Finally, the tongue elongated more with mandibular advancement in subjects with higher AHI. Low AHI was associated with en bloc forward movement of the posterior tongue, but high AHI was associated with minimal movement of the posterior tongue. This difference was independent of BMI. This study suggests that there are two mechanisms by which mandibular advancement improves airway collapsibility in some OSA patients, firstly by en bloc antero-posterior motion of the tongue in subjects with lower AHI and secondly by increasing lateral airway dimensions via a direct connection from the lateral ramus of the mandible.

Early studies suggested that the MAS increased the space between bony structures and provided increased room for soft tissues,² but recent research has shown that the action is more complex with substantial inter-subject variation. Lateral cephalometry demonstrated that mandibular advancement increases the antero-posterior dimensions of the oropharynx^{6,21,22} but has variable effects on the nasopharynx. Some studies have shown enlarged antero-posterior dimensions of the nasopharyngeal airway,^{6,21,23,24} others have shown no significant increase.^{22,25} The hyoid moves closer to the mandibular plane,^{10,21,23,25-27} but with a wide range of direction and amount of movement.²⁸ Mandibular advancement changes airway shape,^{6,16} which can increase airway stability in some subjects.²⁹ Oliven and colleagues¹¹ suggested that mandibular advancement may optimize the mechanics of the tongue so that the fibers are closer to their most efficient mechanical length. The elongation of the tongue dem-

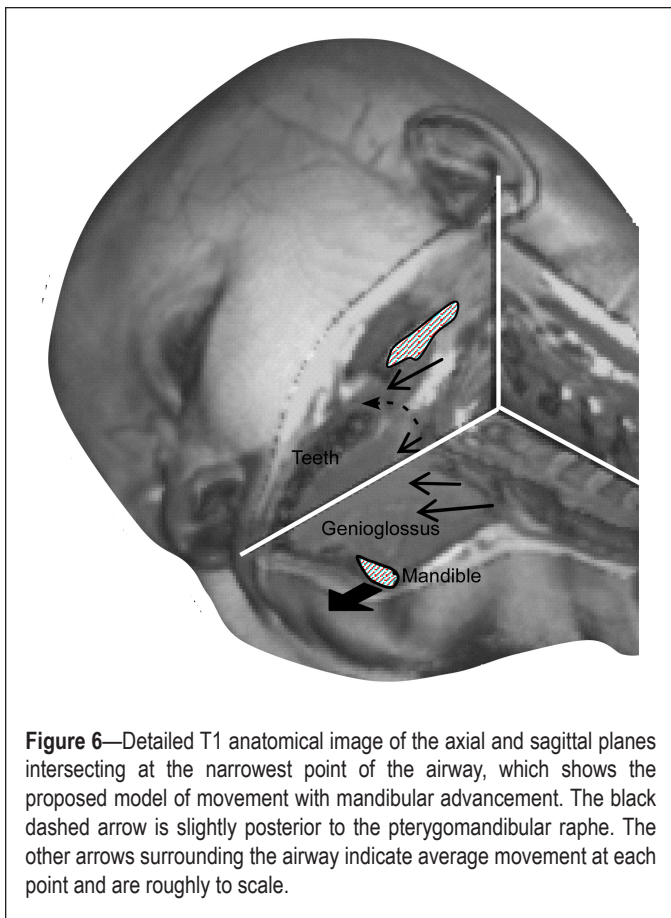


Figure 6—Detailed T1 anatomical image of the axial and sagittal planes intersecting at the narrowest point of the airway, which shows the proposed model of movement with mandibular advancement. The black dashed arrow is slightly posterior to the pterygomandibular raphe. The other arrows surrounding the airway indicate average movement at each point and are roughly to scale.

onstrated here in the antero-posterior dimension could produce this effect.³⁰

Movement of tissues with mandibular advancement is influenced by anatomical and physiological differences between subjects and possibly altered local mechanics related to fat deposition and mouth opening.^{27,31} The inverse correlation between elongation of the nasopharyngeal tongue and AHI adjusted for BMI, although significant, accounted for less than half of observed variation ($R^2 = 0.16$), which suggests other factors also influence how the tongue responds to mandibular advancement. Previous imaging studies have not found clinically useful variables that consistently predict response to MAS, but suggest that MPA, neck circumference,³ mandibular retrognathism,³² distance of the hyoid from the mandibular plane,¹⁶ nasopharyngeal airway space and oropharyngeal site of collapse⁵ correlate with response. Here, the pattern of tongue deformation during mandibular advancement was significantly associated with AHI but not BMI. The en bloc movement associated with low AHI suggests the tongue deforms less and mandibular advancement increases airway size along its length in these subjects. The amount of movement at the nasopharyngeal point was significantly negatively correlated with BMI, possibly due to increased load from the combined effects of increased extraluminal positive pressure and negative pressure in the airway. OSA patients have an elevated critical pressure of the upper airway, which is related to BMI.³³ Fat deposition in the tongue may also have a structural effect to decrease motion.³⁴

Internal deformation of the tongue with mandibular advancement has not been characterized previously. Although computer

modeling suggests that mandibular advancement may rotate the tongue in the sagittal plane,³⁵ we found no evidence of tongue rotation. This study showed evidence of the tongue acting as a muscular hydrostat.^{17,36} The area of the tongue grid in the sagittal plane was not different pre and post mandibular advancement. In a muscular hydrostat, the shape changes but the volume remains constant.³⁶ Thus, deformation of the tongue base influences the whole tongue. In this study, elongation of the posterior tongue base produced supero-inferior compression, in keeping with the tongue acting as a muscular hydrostat. Superior movement of the tissues could be explained by increased tension in the ligaments supporting the tongue from the skull base, but our data suggest this is less likely because the ligaments are lateral to the movement observed (see also below).

Mandibular advancement increases the cross sectional area of the nasopharynx.⁶⁻¹⁰ The lateral walls of the airway are more compliant than the tissues anterior to the airway^{13,37} and are increasingly recognized as important in the pathogenesis of OSA. CT,³⁸ MRI,^{8,10,16} and nasoendoscopic examinations^{6,7,9} demonstrate that mandibular advancement increases the nasopharyngeal lateral dimension airway more than the antero-posterior dimension. The apparent connection between the mandible and the lateral airway walls in this study might explain this. The axial videos through the nasopharynx presented here suggest a direct connection between the lateral walls and the ramus of the mandible. This has not been demonstrated before, although Isono et al. proposed that tongue advancement influenced the soft palate via the pharyngeal arches.⁶ A number of structures may be involved, but we speculate that the pterygomandibular raphe, an aponeurotic connection between the buccinator muscle and the superior pharyngeal constrictor, is a likely candidate after comparing the tagged images with detailed anatomical images and anatomical references.³⁹ It attaches superiorly to the hamulus of the medial pterygoid plate and inferiorly to the mylohyoid line of the mandible but is absent in 36% of subjects.³⁹ When absent, the superior pharyngeal constrictor is continuous with buccinator.³⁹ It is unknown if the presence of a fascial component to this structure affects compliance in the lateral walls, but if it does, then its absence in some patients could influence the clinical response to MAS. We tried to identify a tendinous structure in the presumed region of pterygomandibular raphe as described in anatomical studies,³⁹ but the MRI appearance of the pterygomandibular raphe is not well described, so we were unable to make firm conclusions. There are also a number of ligaments which run infero-anteriorly from the skull base to the ramus of the mandible in the lateral region, including the sphenomandibular ligament. The parasagittal plane was included in our experimental protocol to investigate the role of supero-inferior connections from the skull base in the region of lateral movement. They appeared less likely to explain lateral movement because there was minimal movement in the direction of these ligaments.

Our technique has limitations in addition to being conducted during wakefulness. First, our results are two-dimensional images of three-dimensional structures. In each plane there is the possibility of out-of-plane movement. While a number of planes were imaged, there was insufficient time to image the whole airway in three dimensions. Furthermore, despite instructions to remain passive, some voluntary and reflex muscle

activation^{14,15} in response to the dynamic movement is possible, and this may be different to the effect of a static advancement during sleep, where tissues are likely to relax over time. Also, MAS holds the tissues in a static position during sleep, so our results may not reflect the position of the tissues with MAS in situ. We were unable to recruit a significant subset of subjects who subsequently had MAS treatment, so could not draw conclusions about MAS response. Hence further studies are needed to look at whether different movement patterns and/or the presence of the pterygomandibular raphe can influence clinical response to MAS. Also, the study was only powered to find large effects that were more likely to be clinically significant.

Dynamic imaging has revealed the movement of the tissues surrounding the airway with mandibular advancement and allowed us to quantify movement of the tongue in response to mandibular advancement during wakefulness. It revealed a likely connection between the lateral walls of the airway and the mandible at the nasopharyngeal level. The nature of this connection and the pterygomandibular raphe are new targets for investigation of the etiology of OSA and response to MAS. The internal deformation of the tongue with mandibular advancement was characterized here for the first time. The pattern of deformation of the tongue related to AHI and increased AHI was associated with increased elongation of the tongue independent of BMI, suggesting increasing OSA severity is associated with differences in upper airway mechanics, which may lead to unfavorable treatment outcome with MAS.

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DISCLOSURE STATEMENT

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