

Nasal vestibule wall elasticity: interactions with a nasal dilator strip

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Amis, T. C., J. P. Kirkness, E. Di Somma, and J. R. Wheatley. Nasal vestibule wall elasticity: interactions with a nasal dilator strip. *J. Appl. Physiol.* 86(5): 1638–1643, 1999.—We studied the effect of an adhesive external nasal dilator strip (ENDS) on external nasal geometry in 20 healthy Caucasian adults (10 men, 10 women; age 21–45 yr). The recoil force exerted by ENDS was estimated by bending the device ($n = 10$) with known weights. In the horizontal direction, a small/medium-sized ENDS in situ exerted a unilateral recoil force of 21.4–22.6 g. Application of ENDS resulted in a displacement of the lateral nasal vestibule walls that had both anterosuperior and horizontal components and that was maintained over an 8-h period. The resultant unilateral nasal vestibule wall displacement at the tip of the device was at $47.6 \pm 2.0^\circ$ to the horizontal (as related to the plane of the device when in situ) and had a magnitude of 3.5 ± 0.1 mm. ENDS increased external nasal cross-sectional area by 23.0–65.3 mm². Nasal vestibule wall compliance was estimated at 0.05–0.16 mm/g. Thus ENDS applies a relatively constant abducting force irrespective of nasal width. Variable responsiveness to ENDS may be related to differences in elastic properties of the nasal vestibule wall.

upper airway; pressure-flow relationships; nasal wall compliance

THE ADHESIVE EXTERNAL NASAL DILATOR STRIP (ENDS) has recently come into popular usage as a simple mechanical means of modifying nasal airflow resistance (3, 4, 8). These strips are manufactured with two parallel polyester flat springs enclosed by an adhesive tape covering. When properly positioned over the bridge of the nose, this device reportedly exerts a trusslike force lifting the skin (via the adhesive connection) over the lateral nasal vestibule walls. Transmission of this force to the internal nasal walls then results in an increase in the cross-sectional area of the nasal airway at the level of the nasal valve (3, 8).

The ENDS device has been advocated for therapeutic modification of nasal airflow resistance in a variety of conditions associated with symptoms of nasal obstruction (8). Consequently, the device has found application in the reduction of snoring (9), the improvement of sleep quality (10), the relief of symptoms associated with nasal congestion (e.g., in allergy, viral infections, and pregnancy), and alleviation of breathing difficulties associated with deviated nasal septum and collapsed nasal cartilages (8, 12). In addition, ENDS has also been widely adopted by athletes from many different

sports in an attempt to promote nasal route breathing during competition (11).

The effect of ENDS on nasal airflow resistance is not well understood. The ENDS device has been shown to lower mean nasal airflow resistance by ~23% during relaxed tidal breathing in normal subjects in some studies (4, 8) but has had no effect in other studies (6, 13). However, a feature of these investigations is the marked intersubject variation in the response to ENDS; e.g., in the study by Havas and co-workers (4), ENDS resulted in a fall in nasal airflow resistance that varied in magnitude among subjects from 0 to 43%.

The origins of this variability in the effectiveness of ENDS among subjects has not been investigated. In particular, there have been no studies addressing the nature of the forces exerted by the device on the lateral nasal walls, nor have the resultant alterations in external nasal geometry been characterized. In the present study, we examine individual subject nasal vestibule wall-ENDS interactions by estimating the forces applied to the lateral nasal walls by the ENDS device and measuring the resultant external nasal wall displacements. In addition, we have used the unique mechanical characteristics of the ENDS device to examine lateral nasal vestibule wall elasticity, a property that may be important in determining individual responsiveness to the device.

METHODS

We studied 20 healthy Caucasian adults (10 men, 10 women; age 21–45 yr; height 175.0 ± 6.9 cm; weight 69.7 ± 15.2 kg), none of whom had any symptoms of nasal obstruction at the time of the study. Informed consent was obtained from each subject, and the protocol was approved by the Western Sydney Area Health Service Ethics Committee.

Nasal dilator strips. The ENDS used in the present study is a commercial product (Breathe Right, 3M, Sydney, Australia) available in two different sizes (small/medium and medium/large). The small/medium-sized device was used in the present study. According to the manufacturer's specifications, the device should be positioned midway over the nose with the tape covered springs extending down the external lateral nasal walls along the nasal crease. The tabs at each end of the nasal strip should be adhered to the flare of each nostril. In the present study, all ENDS were applied by the same operator in accordance with the above directions.

Elastic recoil forces generated by ENDS. We measured the outward recoil forces exerted by ENDS at the tips of the polyester springs by bending the device in a specially constructed apparatus (Fig. 1). By using this apparatus, it was possible to bend the ENDS by applying known weights to a moveable platform of known weight (total applied weight 3.3–43.7 g), thus compressing the ENDS, which was fixed vertically in place between the platform and the base of the apparatus. By progressively increasing the weight applied to

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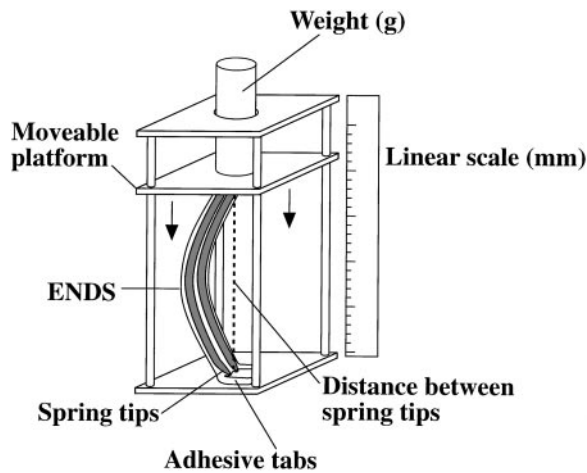


Fig. 1. Schematic diagram of apparatus used to measure recoil forces exerted by adhesive external nasal dilator strip (ENDS) device. Arrows indicate direction of compression of ENDS.

the ENDS and measuring the resultant vertical distance between the tips of the polyester springs (zero spring tip distance measured with no applied force), an outward recoil force vs. distance between spring tips relationship for each device was developed. Ten small/medium ENDS were studied in this manner.

Lateral nasal wall displacements. Subjects wore specially prepared ENDS with equidistant (5-mm) calibration marks (Fig. 2). With the strip in situ, nasal width (average of 2 measurements) at the level of each calibration mark was obtained by using calipers.

During nasal width measurement, subjects rested their chin on a support and breathed via the oral route. The calibration marks were then extended onto the subject's skin, and the ENDS was removed. Approximately 2–5 min later, the nasal width measurements were repeated.

On a separate occasion, five of the subjects underwent hourly measurement of nasal width at the level of the in situ ENDS spring tips while wearing an ENDS over a continuous period of 8 h.

Data analysis. A recoil force-distance between spring tips plot for ENDS was developed by plotting the mean distance between spring tips vs. the applied force. By using standard geometric analysis, nasal width measurements were used to reconstruct the cross-sectional shape of the nose in the anterosuperior-to-posteroinferior plane formed by the ENDS device when it is attached to the nose (Fig. 3). For the purposes of this analysis, it was assumed that displacements were symmetrical and that the distance between calibration marks on both the ENDS device in situ and the external surface of the nasal wall could be represented by a straight line (Fig. 4). Nasal width data were corrected for the thickness of the ENDS device.

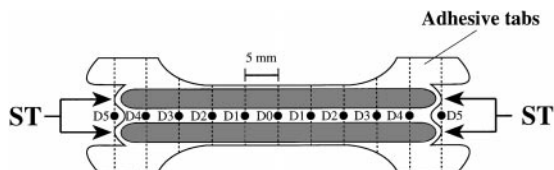


Fig. 2. Diagrammatic representation of small/medium-sized ENDS device showing equidistant 5-mm calibration marks (dashed lines, D0–D5) used to define levels at which nasal width was measured with device in situ. ST, tips of polyester springs (shaded areas) within ENDS device.

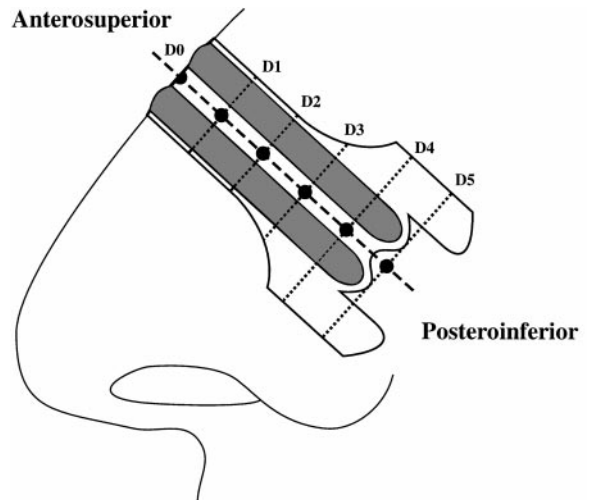


Fig. 3. Schematic diagrams showing lateral view of ENDS device in situ on nose. Note anterosuperior-to-posteroinferior plane (dashed line) described by positioning of device on external surface of nose. Geometric reconstructions of external nasal cross-sectional shape were performed in this plane from measurements of nasal width performed at level of calibration marks on ENDS device (dotted lines, D0–D5).

The effect of ENDS on external nasal geometry was examined by 1) comparing nasal width measurements at the spring tips with and without ENDS; 2) calculation of the anterosuperior, horizontal, and resultant displacement vectors at the level of the spring tips; 3) calculation of the force vectors operating at the spring tips (achieved by relating the distance between the spring tips in situ to the recoil force vs. distance between spring tips plot developed for the device); and 4) calculating the cross-sectional area of the nose (from nasal shape reconstructions) with and without ENDS (Fig. 4). In addition, by relating the recoil force developed by the device to the nasal width change achieved at the spring tips,

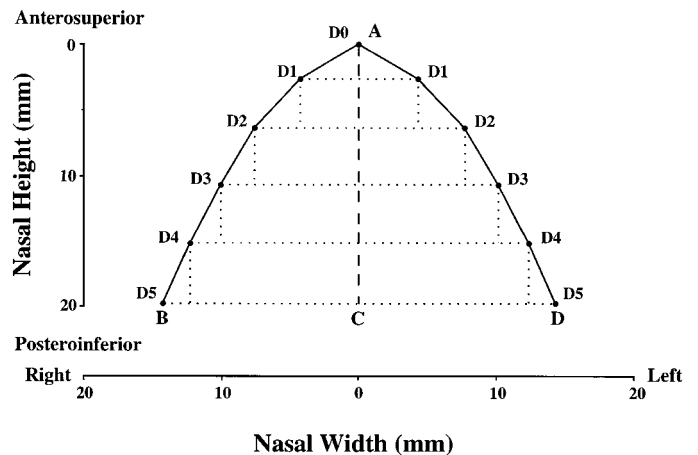


Fig. 4. Schematic diagram showing geometric model (2-dimensional plot of nasal dimensions) used to reconstruct external nasal cross-sectional shape from nasal width measurements. Assuming symmetry about midline (dashed line) and straight-line approximation between adjacent calibration marks (D0–D5) on ENDS, nasal dimension in anterosuperior-to-posteroinferior plane (nasal height) was calculated at each nasal width measurement level (by using standard geometric constructions, dotted lines) and external cross-sectional shape of nose was reconstructed. Origin (0,0) was set at D0 (center of ENDS on bridge of nose). Cross-sectional area of nose was taken as area ABCDA.

we examined the elastic properties of the lateral nasal wall by calculating a value for lateral nasal vestibule wall compliance (i.e., linear displacement per unit force) for each subject.

Serial measurements of nasal width over time were compared by using repeated-measures analysis of variance. Scheffé's test was used as a post hoc multiple-comparison technique. Single comparisons were made by using a paired or unpaired *t*-test as appropriate. The influence of age on lateral nasal wall compliance was examined by using simple linear regression analysis. *P* < 0.05 was taken as significant.

RESULTS

Recoil force generated by bending the ENDS device.

The recoil force vs. distance between spring tips plot generated by bending ENDS with known weights is shown in Fig. 5. These plots were characteristically sigmoid in shape with little bending occurring until a force of ~20 g was applied. The device then became unstable with large changes in the distance between spring tips occurring as the bending force was increased from 20 to 25 g. Thereafter, the device again became more difficult to bend with the spring tip distance changing by only ~11 mm with a 76% increase in the applied force from 25 to 44 g. Of particular interest, however, is the relationship between the distance between spring tips and the recoil force over the 20- to 45-mm distance. Over this range, the recoil force produced by the device was virtually constant at 20–25 g.

Lateral nasal vestibule wall displacement at distal tip of ENDS. Without ENDS the group mean nasal width (measured at the site where the distal tip of the ENDS was positioned for ENDS studies) was 29.7 ± 0.3 mm (range 25.5–32.4 mm). With ENDS the lateral nasal wall was displaced outward in all subjects and nasal width increased significantly to 34.5 ± 0.2 mm (range 32.5–36.5 mm; *P* < 0.0001; Fig. 6).

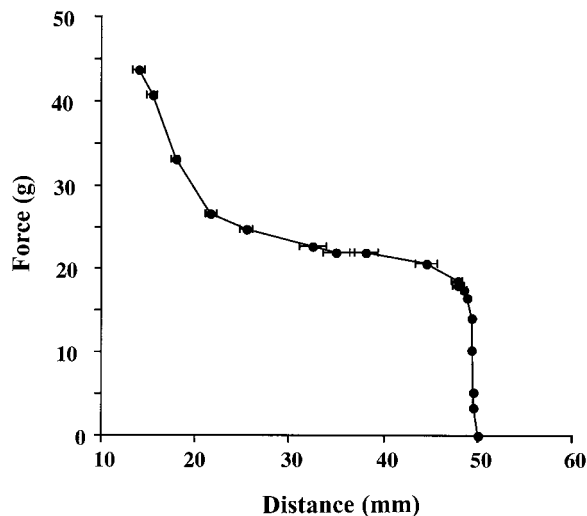


Fig. 5. Mean recoil force vs. distance between spring tips plot obtained from bending 10 small/medium ENDS devices. Values are means ± SE. Note reproducibility of force-distance characteristics between devices and sigmoid shape of plot such that over distance range 45–20 mm recoil force generated by device is virtually constant at 20–25 g.

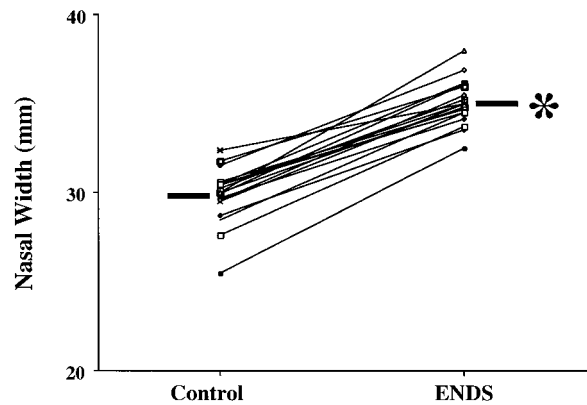


Fig. 6. Nasal width measurements at the level of the ENDS spring tips in situ in 20 normal subjects with (ENDS) and without ENDS (control). Note that nasal width increased in all subjects. Different symbols represent individual subjects. Bars, mean value. **P* < 0.0001.

Nasal cross-sectional shape changes induced by ENDS. The ENDS device induced a change in external nasal cross-sectional shape in all subjects. Typically, this involved an increase in external nasal width at all levels, with changes toward the bridge of the nose being minimal and those at the spring tips being maximal in most subjects (Fig. 7). The other consistent feature was upward and anterior (i.e., anterosuperior) displacement of the external surface of the nose, again at a minimum toward the bridge of the nose and a maximum at the spring tips.

Displacement vector analysis. When the displacement of the skin at the distal spring tip site was examined in terms of both its anterosuperior and horizontal components, it was found that the resultant displacement vector was at a mean angle to the horizontal (as related to the plane of the device when in situ) of 47.6 ± 2.0° (range 31.8–63.7°). The mean unilateral horizontal displacement was 2.4 ± 0.1 mm, the mean

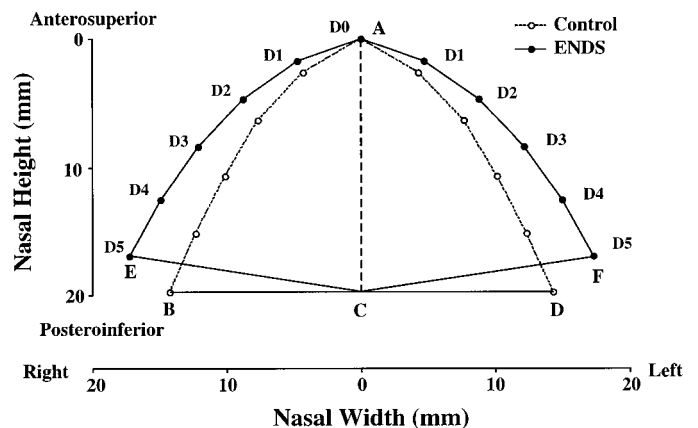


Fig. 7. Nasal cross-sectional shape obtained with (ENDS) and without ENDS (control) in 1 subject. Typically, ENDS resulted in an anterosuperior and horizontal movement of external surface of lateral nasal walls at all levels and with larger displacements occurring at level of spring tips (i.e., D5). External nasal cross-sectional area was calculated as the area ABCDA during Control and the area AECFA with ENDS. Definitions of D0–D5 are as in Fig. 4. Dashed line, midline.

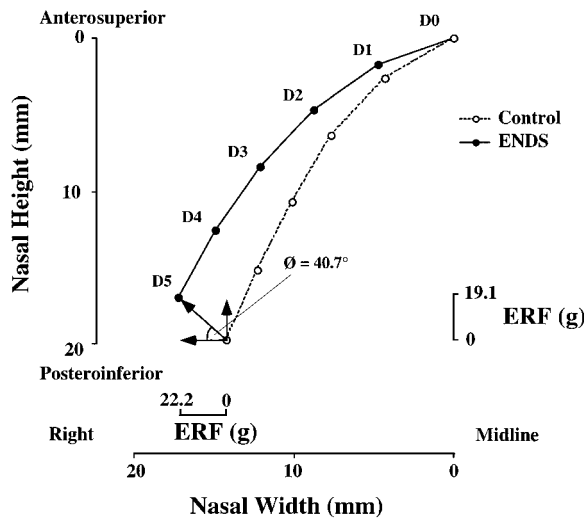


Fig. 8. Plot showing magnitude and direction of calculated nasal wall displacement and ENDS recoil force (ERF) vectors (arrows) operating unilaterally on external nasal wall at level of spring tips (D5) of small/medium ENDS device in 1 subject. Unilateral external nasal cross-sectional shape is shown with (ENDS) and without ENDS (control). Note that resultant vector angle (θ) is at 40.7° to horizontal plane. ERF scale applies only to vector analysis. Definitions of D0–D5 are as in Fig. 4.

anterosuperior displacement was 2.6 ± 0.1 mm, and the mean resultant vector displacement was 3.5 ± 0.1 mm. An example of a displacement vector analysis is shown in Fig. 8.

Recoil forces exerted by ENDS. When the individual distance between spring tips for the ENDS, measured with the device in situ, was related to the distance between spring tips vs. recoil force plot for the device (see Fig. 5), the average horizontal force exerted by the ENDS device was found to be 22.0 ± 0.1 g (range 21.4–22.6 g). Vector analysis of the forces acting on the skin at the spring tips revealed an average anterosuperior force component of 25.5 ± 1.9 g (range 13.8–44.0 g) and an average resultant force vector of 34.1 ± 1.4 g (range 26.1–49.2 g). An example of a force vector analysis is shown in Fig. 8.

External nasal cross-sectional area. The ENDS device increased external nasal cross-sectional area in all subjects (see Fig. 7). For the group, mean cross-sectional area was 366.4 ± 2.4 mm² (range 344.4–385.4 mm²) without ENDS and increased significantly to 411.2 ± 1.8 mm² (range 396.0–425.7 mm²; $P < 0.0001$) with ENDS. Thus ENDS increased external nasal cross-sectional area by 44.8 ± 2.3 mm² (range 23.0–65.3 mm²).

Lateral nasal vestibule wall compliance. Calculated unilateral nasal vestibule wall compliance measured at the distal tip of the ENDS ranged from 0.05 to 0.16 mm/g (Table 1). The group mean value was 0.11 ± 0.01 mm/g. There was no significant difference between men and women ($P = 0.6$), nor was there any significant correlation between lateral nasal wall compliance and age ($r = 0.06$, $P = 0.8$).

Time course of ENDS-induced nasal width changes. Nasal width increased with application of ENDS in all five subjects studied (29.9 ± 0.4 – 34.0 ± 0.5 mm; $P <$

0.05). Thereafter, there was no significant change in nasal width over an 8-h period ($P > 0.9$).

DISCUSSION

The principal findings of this study were 1) in the horizontal direction, ENDS exerted a constant unilateral recoil force of 21.4–22.6 g over a distance of 20–45 mm between the spring tips; 2) application of ENDS to the nose of normal subjects resulted in a displacement of the external surface of the lateral nasal vestibule walls (in all subjects) that had both anterosuperior and horizontal components; 3) when measured at the spring tips of the ENDS device in situ, the resultant unilateral nasal wall displacement vector was at $47.6 \pm 2.0^\circ$ to the horizontal and had a magnitude of 3.5 ± 0.1 mm; 4) ENDS increased external nasal cross-sectional area by 23.0–65.3 mm²; 5) nasal vestibule wall compliance (measured in the horizontal direction) ranged from 0.05 to 0.16 mm/g in the subjects studied; and 6) the lateral nasal vestibule wall displacements associated with wearing an ENDS were maintained over an 8-h period.

An interesting feature to emerge from our examination of the recoil forces exerted by the ENDS device was the flat response over the 20- to 45-mm distance between spring tips (see Fig. 5). This distance encompasses the range of nasal widths (25.5–32.4 mm) encountered in the present study. Thus it would appear that the ENDS device is isotonic in nature in that it exerts approximately the same lateral force on noses of varying width, at least within the range of nasal widths encountered in Caucasians. Other ethnic groups are

Table 1. Nasal width measured during control and ENDS together with estimated horizontal ENDS recoil force and lateral nasal vestibule wall compliance

Subject No.	Control, mm	ENDS, mm	Change, mm	Force,* g	Compliance,† mm/g
1	30.9	33.1	2.3	21.8	0.05
2	28.7	33.5	4.8	22.4	0.11
3	30.0	34.8	4.8	22.2	0.11
4	28.5	34.0	5.5	22.2	0.12
5	30.0	36.5	6.5	21.8	0.15
6	27.6	33.7	6.1	22.6	0.14
7	31.1	33.7	2.6	22.0	0.06
8	29.0	34.0	5.0	21.9	0.11
9	30.4	35.0	4.6	22.4	0.10
10	30.5	34.5	4.0	21.7	0.09
11	30.3	35.4	5.1	22.0	0.12
12	29.5	35.0	5.5	21.7	0.13
13	32.4	35.0	2.7	22.0	0.06
14	30.4	34.5	4.1	21.8	0.09
15	25.5	32.5	7.0	22.2	0.16
16	28.5	34.5	6.0	22.2	0.13
17	30.5	34.5	4.0	21.7	0.09
18	29.7	34.1	4.5	22.3	0.10
19	31.8	36.0	4.2	21.4	0.10
20	29.6	35.5	5.9	22.2	0.13

Mean \pm SE 29.7 \pm 0.3 34.5 \pm 0.2 4.8 \pm 0.3 22.0 \pm 0.1 0.11 \pm 0.01

ENDS, adhesive external nasal dilator strip. *Obtained from Fig. 5. †Nasal vestibule wall compliance is calculated as one-half the change in nasal width (Change) divided by estimated force (Force) because the force estimate is obtained unilaterally, whereas the nasal width is a bilateral measurement.

known to have significantly different external nasal dimensions (particularly nasal width) compared with Caucasians (1, 7), and this may have the potential to influence the force exerted by ENDS on the lateral nasal vestibule walls in these groups.

The lateral force exerted on the nose by the ENDS device was ~ 22 g. This represents around the same force as is exerted by human nasal dilator muscles during exercise involving nasal-only breathing (2). Thus it appears that the ENDS device exerts forces on the lateral nasal walls that are compatible with the normal physiology of the nose.

There have been no previous studies examining the change in external nasal geometry associated with the application of the ENDS device. Application of ENDS altered the external nasal geometry in all subjects studied. Typically, the lateral nasal wall moved outward (horizontal component) and upward (anterosuperior component) at all levels. At the level of the spring tips, the resultant displacement of the skin was at an average 47.6° to the horizontal. This pattern of displacement of the lateral nasal walls resulted in an increase in external nasal cross-sectional area in all subjects.

By using acoustic rhinometry, Griffen and co-workers (3) found an average bilateral increase of 30 mm^2 in the internal nasal valve cross-sectional area with ENDS. However, there was some variation in the response with the change in cross-sectional area being less in blacks (20 mm^2) than in whites (36 mm^2). Similarly, Roithmann and colleagues (8) found an average unilateral increase in nasal valve cross-sectional area of 12 mm^2 in healthy subjects with ENDS. In the present study, bilateral external cross-sectional area increased by an average of 44.8 mm^2 . Thus, as might be expected, the changes in external nasal airway cross-sectional area appear to be somewhat greater than reported changes in internal nasal airway lumen cross-sectional area at the level of the nasal valve. Indeed, by comparing the results of the reported changes in intraluminal cross-sectional area for whites in the study by Griffen and co-workers (3) with the external measurements made in the present study, it would appear that, in Caucasians, on average, some 20% of the effect of ENDS on the exterior of the nose may not be transmitted to the nasal valve lumen.

An important feature of the present study was the variation in the magnitude of the response to ENDS, with between-subject changes in cross-sectional area ranging from 23.0 to 65.3 mm^2 . Assuming an 80% transmission of this change to the internal nasal airway, it might be expected that for the individuals in the present study, the change in bilateral intraluminal nasal valve cross-sectional area may have been as small as 18 mm^2 and as large as 52 mm^2 . This compares with values of 24 – 56 mm^2 calculated from results reported by Roithmann and co-workers (8).

Because the lateral force exerted by the ENDS device was approximately the same for all individuals, the cause of the intersubject variability in responses must lie in the interaction between the device and individual nasal wall physiology. Lateral nasal vestibule wall

compliance averaged 0.11 mm/g but ranged from 0.05 to 0.16 mm/g and was unaffected by gender or age. There has been only one previous study of nasal wall elastic properties. By using acoustic rhinometry to determine nasal intraluminal volume, and with subjects actively altering intraluminal nasal airway pressure, Kesavanathan and co-workers (5) estimated the nasal volume-to-intraluminal pressure ratio at the level of the nasal valve in six normal subjects. They found a fourfold variation in nasal valve compliance, which ranged from 0.03 to $0.12 \text{ cm}^3/\text{cmH}_2\text{O}$.

This inhomogeneity in nasal wall elastic properties in healthy adults, and the potential resultant variability in the change in external nasal cross-sectional area with ENDS, may be an important factor in determining the effect of ENDS on nasal airflow resistance in any given individual. Furthermore, individuals with more compliant nasal vestibule walls may be more susceptible to nasal wall collapse (subject to the effects of alae nasi recruitment) at higher ventilatory levels and, therefore, may benefit from the nasal wall stabilization effects of ENDS during, for example, exercise.

Because ENDS is advocated for the reduction of snoring (9), it may be worn overnight while subjects are asleep. In the present study, we tested the ability of the device to maintain a change in external nasal geometry over an 8-h period. In all five subjects tested, nasal width (measured at the level of the ENDS spring tips) remained within 94% of the value measured within 2 min of application of the device. Thus any effect of ENDS on snoring might be expected to be maintained throughout the night.

We conclude that, at least in Caucasians, ENDS-associated external lateral nasal wall displacements may vary among individuals because of differences in lateral nasal wall compliance and not because of differences in the applied force. Hence, individual responsiveness to the device may, at least in part, be related to intersubject differences in the elastic properties of the lateral nasal vestibule walls. However, external changes in nasal dimensions with ENDS may not translate to equivalent changes in intraluminal geometry at the nasal valve, which is the site of interest. Last, the unique properties of the ENDS device provide a simple approach to the estimation of nasal vestibule wall elastic properties.

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