

UPPER AIRWAY MORPHOLOGY AND SIZE ALTERATIONS IN SUPINE AND LATERAL POSITION IN SEDATED PEDIATRIC PATIENTS UNDERGOING CT VIRTUAL ENDOSCOPY EXAMINATION

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Background:

Lateral positioning decreases upper airway obstruction in sleeping, anesthetized and muscle relaxed individuals presumably secondary to gravitational effects.

Methods:

Children aged 2-6 yr, requiring computed tomography (CT) examination of the head or neck region, were studied using deep sedation with Ketamine/Midazolam 20:1. Exclusion criteria included any type of anatomical or neurologic entity that could influence upper airway shape or size. Axial spiral CT sections of the upper airway were obtained in the supine and lateral positions, with the head and neck axes maintained neutral. Using advanced GE workstation AW4.0, the CT images were processed to render a three-dimensional reconstruction and virtual endoscopic images of the upper airway. Total airway volumes and cross-sectional areas were computed between the nasal vomer and the vocal cords. Two-way paired t tests were used to compare airway sizes between supine and lateral positions.

Results:

The total airway volume (mean \pm SD) was 6.6 ± 3.3 ml in the supine position and 9.5 ± 3.1 ml in the lateral position ($P < 0.001$) in seventeen of 18 children analyzed. Maximal relative percent airway increase was at the region between the tip of the epiglottis and vocal cords.

Conclusion:

This study confirms the well-known clinical observation that sedated children practice less upper airway obstruction in the lateral position when compared with the supine position. This widening occurred at all non cartilaginous areas of the upper airway and was most pronounced in the region at and below the tip of the epiglottis.

Keywords: *airway, endoscopy, virtual; position, supine, lateral*

Introduction:

Variable factors decreasing upper airway obstruction in vulnerable subjects have been addressed by several investigators in the vicinity of sleep apnea. Amongst these factors is positioning. Lateral positioning reduces upper airway obstruction in muscle relaxed, sedated adults and in individuals under anesthesia and those with sleep apnea.^{1, 2, 3, 4}

The protective reflexes, of the dilators of the pharynx, are of vital importance in preventing pharyngeal collapse. Malfunction of these reflexes is involved in the pathogenesis of obstructive sleep apnea. Contradictory evidence exists in the literature concerning how responsive these muscles are during stable phase of non-rapid eye movement sleep. However, differences in positioning in previous studies may have affected these findings. It was suggested that the muscles protruding the tongue are maximally receptive to negative pressure pulses during sleeping in supine position, where displacement of the tongue posteriorly accounts for the pharyngeal occlusion.²

Effects of jaw thrust and chin lift on airway patency were greatly enhanced in the lateral position than in the supine position where these airway patency maneuvers, combined with lateral positioning, proved ideal for maintaining airway patency.³

Decrease of night-time obstructive attacks in the lateral posture in patients with obstructive sleep apnea has formerly been reported. Nevertheless, modest information is available concerning mechanisms of the improvement and the precise pharyngeal region affected by the lateral posture. It was postulated that the structural characteristics of the passive pharyngeal airway change by changing the body position from supine to lateral.⁴

A virtual laryngoscopy system for interactive rendering and three dimensional visualization of the upper airway and laryngeal framework is established. This system runs on regular computer workstations supporting major window systems using CT data from normal subjects.^{5, 6}

All non cartilaginous regions of the upper airway become considerably larger with the plane at or below the tip of the epiglottis showing the largest relative percent change.⁷ in the supine

posture, gravity forces the upper airway to be more restricted by neighboring anatomical structures when compared with the lateral posture.⁴

It was postulated that lateral positioning augments upper airway cross-sectional area and total upper airway volume when compared with the supine position in sedated, spontaneously breathing pediatrics.⁷

The main aim of this investigation was to demonstrate the alterations in upper airway anatomy that occur when sedated, spontaneously breathing children are located in the lateral posture.

Materials and Methods:

Children aged 2-6 yr requiring CT examination of the head or neck region using deep sedation were eligible for inclusion. They were randomly enrolled, using closed envelope randomization blocks, to either left or right lateral position after supine position. The protocol was approved by The Cairo University Hospital Research Review Board. Written consent was obtained from all parents, and verbal agreement was attained from children when appropriate. Exclusion criteria included acute or chronic lung ailment, upper airway dysfunction or pathology of any kind, heart disease, obesity (body weight > 90th percentile for age), sleep apnea syndrome, central nervous system (CNS) disease possible to affect muscle tone, any abnormal neck anatomy, or the need for any adjunct airway device (e.g., oral airway, endotracheal tube).

Children were anesthetized before the CT scan and maintained deeply sedated using Ketamine/Midazolam 20:1, where midazolam ameliorates effect of ketamine on airway tone and reflexes as well as on hemodynamics in this ratio⁸, at a starting ketamine dose of 120 micrograms·kg⁻¹·min⁻¹ and a starting midazolam dose of 6 micrograms·kg⁻¹·Min⁻¹. The ketamine/midazolam mixture 20:1 was given as an infusion and titrated based on maintenance of unconsciousness (e.g., lack of spontaneous limb movement) and normal hemodynamic and ventilatory parameters (e.g., within 20% of baseline values). All children were breathing spontaneously without help throughout the whole anesthetic period. Supplemental oxygen was administered by nasal cannula (2 or 3 l/min) in all cases. After finishing

the clinically required scans, the study protocol was performed while the child remained in the supine position. The head and neck rested in the neutral position on a tiny head pillow, without obvious flexion, extension, lateral flexion, or lateral rotation. The extent of mouth opening was not restricted in either position. This positioning protocol was previously applied in other relevant studies.⁷

To study the postural alterations in upper airway morphology, we used a GE light speed multidetector CT device (with advanced workstation AW4.0) that allows three-dimensional imaging of upper airway structures. Virtual endoscopy (VE) is a new diagnostic tool that generates 3-dimensional (3D) views of a lumen by exploiting cross-sectional images. This methodology allows high-quality visualization and quantification of the upper airway volume and cross-sectional area in a correct anatomical orientation. This methodology was used to determine the conformational alterations that occur in the upper airway of anesthetized children when they are positioned in the lateral posture.

The study protocol comprised of helical axial CT of the upper airway from the level of hard palate to the subglottic region (end of larynx) using 3.0-mm slice thickness, pitch of 2.0, reconstructed section overlap of 50%, 175mAs). The CT data for each study were loaded onto a workstation (advanced GE workstation AW4.0). 3D-Doctor software (Able Software Corp Lexington, USA) was also used for volume rendering. The time to conclusion of the study scan was more or less 1 min. At the achievement of the airway scan in the supine position, the patient was turned laterally, to either the left or right lateral positions, according to a randomization protocol, on the CT table. Great concern was taken to ensure that the head and neck were maintained in the neutral position, without flexion, extension, lateral flexion, or lateral rotation. All

other body parts were properly protected, while the subject's body was maintained in a plane at 90° to the axis of the table. After securing the child, the upper airway scans were repeated by means of the same protocol as for the supine scans. After the study scans, the CT images were saved and transferred to the advanced GE workstation where the images were processed and segmented automatically to provide a three-dimensional reconstruction and virtual endoscopic images of the upper airway. Measurements of the upper airway volume and cross-sectional area were also performed. Similar measurements were done in other relevant studies.⁷

Sample Size and Statistical Analysis:

Previous studies postulated that in normal children, the mean cross-sectional area of the upper airway is $47.1 \pm 18.2 \text{ mm}^2$ (mean \pm SD).⁷ It was considered that a 30% change in upper airway cross-sectional area would represent a clinically important change. Thus, a sample size of 16 would have 80% power to detect a difference in means of 14 mm^2 using a paired t test with a 0.05 two-sided significance level. We determined differences in total airway volume and cross-sectional areas at multiple pharyngeal levels using two-sided paired t tests.

Results:

Twenty children were enrolled into the study according to inclusion criteria. Nevertheless, only 18 children managed to complete the study protocol. These were 8 boys and 10 girls (9 in the left lateral position, 9 in the right lateral position). Their ages, expressed as mean (range), were 3.7 (2-6 yr) and their weights, expressed as mean (range), were 16.5 (11.1-23.0 kg). Table 1 reveals the diagnosis of each of the studied patients. No adverse events were experienced during the study protocol.

Table 1: Characteristics of All Study Subjects

	Sex	Age, yr	Weight, Kg	Diagnosis	Lateral Decubitus position
1	M	4	17.2	Astrocytoma	Left
2	F	5	20.1	Neurofibromatosis	Right
3	F	3	14.9	Developmental delay	Left
4	M	6	22.8	Ependymoma	Right
5	F	5	21.1	Neurofibromatosis	Left
6	M	3	15.2	Astrocytoma	Right
7	M	4	17.2	Neurofibromatosis	Right
8	F	2	12.1	Temporal glioma	Left
9	M	3	15.2	Seizure disorder	Right
10	F	6	22.3	Cranial nerve III palsy	Right
11	M	2	12.2	Developmental delay	Left
12	F	4	15.8	Neurofibromatosis	Left
13	M	3	14.5	Neurofibromatosis	Right
14	M	6	23	Seizure disorder	Left
15	F	2	11.1	Neurofibromatosis	Right
16	M	4	15.8	Neurofibromatosis	Left
17	F	3	15.3	Seizure disorder	Left
18	F	2	11.5	Neurofibromatosis	Right

No upper airway obstruction or oxyhemoglobin desaturation (<95% oxygen saturation measured by pulse oximetry) were experienced by any patient at any time during the scans. The right and left lateral positions results were comparable. Therefore, they were combined in final data analysis. Seventeen of the eighteen

patients experienced increases in the total volume of their upper airway when positioned in the lateral position. Total airway volume (mean \pm SD) was 6.6 ± 3.3 ml in the supine posture and 9.5 ± 3.1 ml in the lateral posture ($P < 0.001$; Table 2).

Table 2: Seventeen of 18 children had increased volumes in the lateral when compared with the supine position. Total upper airway volume (mm³) was significantly greater in the lateral position ($P < 0.001$).

Subject	Total Airway Volume(ml ³)	
	Supine	Lateral
1	2	5.5
2	3	5
3	3	9
4	4	10
5	4	6.2
6	5	7
7	5	4.8
8	5.1	10
9	5.5	6.1
10	5.7	6.8
11	5.9	9
12	8	13
13	9	12
14	8.5	13
15	8.6	6.4
16	11.5	13
17	12	12.6
18	13.5	13.7

Figure 1 reveals the three-dimensional reconstruction and virtual endoscopic images of the upper airway in supine and lateral positions in one patient using 3D-Doctor.

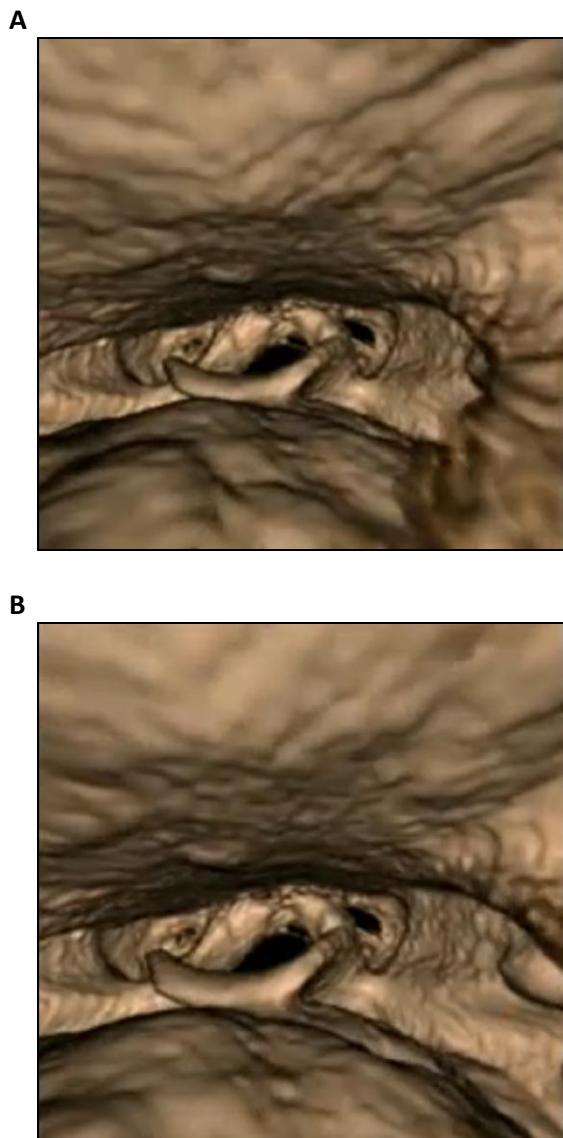


Figure 1: One subject's upper airway in the supine and lateral positions with normal upper airway anatomy, (A) Virtual endoscopic image from the oropharynx in the supine position, (B) Virtual endoscopic image from the oropharynx in the lateral position

Figure 2 illustrates the three-dimensional reconstruction and virtual close-up images of the relationship of aryepiglottic folds to the glottic

opening in both body positions in one of the studied patients.

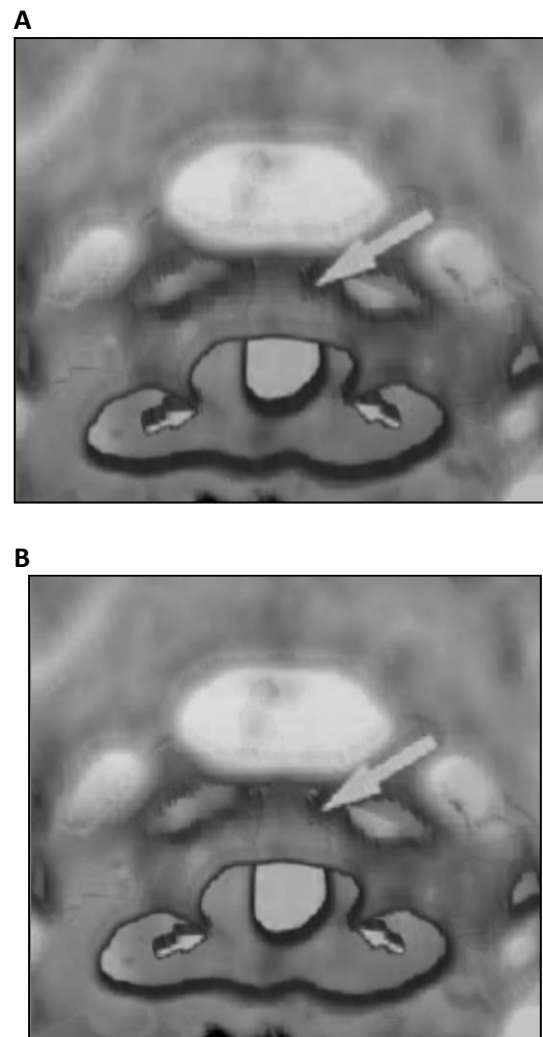


Figure 2: One subject's upper airway in the supine and lateral positions with normal upper airway anatomy, (A) Close-up of relationship of the thin aryepiglottic folds (small arrows) to the glottic opening and preepiglottic fat (big arrow) in the supine position, (B) Close-up of relationship of the thin aryepiglottic folds (small arrows) to the glottic opening and pre-epiglottic fat (big arrow) in the lateral position.

All the non-cartilaginous cross-sectional areas of the upper airway were revealed to be higher in the lateral position than in the supine position (Table 3).

Table3:

Comparison of average cross-sectional areas of the upper airway between supine and lateral positions as a function of location along the airway from nasopharynx and till vocal cords

Length along upper airway in percentiles from nasopharynx and till vocal cords	10	20	30	40	50	60	70	80	90	100	
Average area(mm ³)	Supine	111	88	75*	70‡	85‡	105‡	90‡	70‡	45*	35
	Lateral	117	105	105	115	130	160	160	135	88	55
Percent change from supine (%)	5	19	40	64	53	52	78	93	96	57	

* $P < 0.05$. ‡ $P < 0.01$ as compared to lateral position.

The area between the tip of the epiglottis and the vocal cords showed the highest relative percent change. The percent change from the supine position indicates that the region at or below the tip of the epiglottis reveals the utmost alteration from supine to lateral. The nasopharynx is represented by the retropalatal area and it comprises the region between the vomer and the base of the uvula. The oropharynx is represented by the retroglossal area and it comprises the region between the base of the uvula and the tip of the epiglottis. The body of the epiglottis and arytenoids lies below the tip of epiglottis.

Discussion:

Using multidetector CT analysis of upper airway morphology, the present study revealed that positioning a sedated, spontaneously breathing child in the lateral position enlarges the upper airway.

A real-time approach, using CT data, through automatic segmentation, volume rendering and surface rendering for ultimate visualization of laryngeal framework and upper airway is now available.⁶ In the present study, a relevant virtual laryngoscopy system using 3D doctor software was utilized for conduction of this study. Virtual laryngoscopy has been shown to be a noninvasive potential clinical diagnostic and treatment planning tool for the larynx and upper airway.^{5, 6} In the current study, CT virtual laryngoscopy was so valuable in assessing and measuring the relevant parameters in all the studied subjects.

Clinically, it has been previously confirmed that less upper airway reduction may take place when spontaneously breathing children get deep sedation in the lateral position.⁷ this comes in agreement with the results of the present study.

These conclusions can be justified from anatomical as well as physiological points of views by the results of several other relevant studies. It has been speculated that the genioglossal responsiveness to negative pressure pulses in the non-rapid eye movement sleep is responsible for preventing pharyngeal collapse during supine sleep. Nevertheless, collapsibility, measured during negative pressure pulses, was more in the supine than in the lateral decubitus.² Furthermore, the maximum cross-sectional areas of both the retropalatal and retroglossal airways maximally increased in the lateral position. In addition, it was proved that the lateral position maintains the structural patency of the passive pharyngeal airway in obstructive sleep apnea.⁴ this clearly justifies the findings of the present study from a physiological point of view.

The present study revealed that the upper airway of a sedated, spontaneously breathing child widens in the lateral position. This widening was revealed at all non cartilaginous regions of the upper airway. The area between the tip of the epiglottis and the vocal cords revealed the utmost relative percent amplification in size. This comes in agreement with the results of another study revealing that the width of the upper airway increases in sedated pediatric patients, spontaneously breathing, in the lateral position. Furthermore, the greatest increase in size appeared to be in the area between the tip of the epiglottis and the vocal cords.⁷

Respiratory depression is one of the major adverse effects of anesthetic or sedatives in the pediatric clinical practice. It is evidenced as reduced respiratory drive and, in most circumstances, as failure to maintain a patent upper airway. It may proceed to hypoxemia which threatens life. Conventionally, the

capability of an anesthetic agent to cause respiratory depression has been quantitatively evidenced by measuring its impact on resting carbon dioxide levels and its capacity to change the normal ventilatory response to hypoxia and hypercapnia.⁹ Nevertheless, it is now obvious that these variables are not clinically relevant as apnea and upper airway obstruction are more vital causes of hypoxemia, specially in children.¹⁰ The lateral position is frequently applied in pediatric anesthetic practice during recovery from general anesthesia based on clinical experience.¹¹ Although a randomized clinical investigation to compare between the lateral and the supine postures was not performed, some patients with sleep apnea syndrome experienced less upper airway obstruction when in the lateral position.^{1,2} Thus, it sounds logic to assume that semiconscious patients in the lateral position may exhibit less upper airway obstruction justifying the results of the current studies.

In the study by Litman et al⁷, it was observed that the base of the tongue seemed to be in direct contact with the anterior surface of the epiglottis and thus may have been responsible for posterior epiglottis displacement with consequential narrowing of the airway in this area. In some children sedated with propofol, the region of most narrowing within the upper airway lies at the level of the epiglottis.⁷ Lateral positioning reduced this area of narrowing, presumably by a gravitational effect.⁷ This comes in agreement with the present study conclusions.

The shape of the pediatric upper airway was shown to be altered significantly on awakening from propofol sedation. It appeared oblong shaped with the transverse diameter smaller than the antero-posterior diameter on sedation. On recovering, the shape mostly changed such that the antero-posterior diameter was smaller although cross-sectional areas between sedated and recovery states were unchanged. These changes may be due to the differential effects of propofol on upper airway muscular tissues during recovery.¹² In the present study this effect of anesthetics tended to be nullified by the use of 20:1 ketamine / dornicum in an attempt to abolish the effect of anesthetics on pharyngeal tone.

Body position, rather than the sleep stages, strongly affects the upper airway collapsibility. Therefore, lower CPAP pressure is needed, in the lateral than in the supine position, to maintain a patent upper airway.¹ Nevertheless, in the present study, the level of sedation was attempted to be maintained all through the study to abolish any effect of level of sedation on upper airway size or morphology.

Using the advanced CT workstation, it was revealed, in the present study, that the upper airway of sedated, spontaneously breathing children enlarges significantly in the lateral position versus in the supine position. Thus, it emphasizes the widespread clinical incident that sedated children experience less upper airway obstruction in the lateral decubitus when compared with the supine decubitus.

Recent updates in 2-dimensional and 3-dimensional volume reconstruction, external rendering techniques, with virtual bronchoscopy generated instantly, invaluablely supplemented the traditional axial CT imaging for detection of various airway disease including airway stenoses, neoplasms, and congenital disorders.¹³ These techniques were maximally utilized and performed in the present study to achieve the required data and reach our conclusions.

The glottic opening was better visualized by flexible nasal laryngoscopy when chin lift and jaw thrust maneuvers were combined with continuous positive airway pressure in spontaneously breathing, anesthetized pediatric patients.¹⁴ The present study provides a probable illustrative mechanism for the improvement of upper airway obstruction by submission of manual anterior mandibular advancement (jaw thrust) in sedated children. This maneuvers increase the oropharyngeal area at the level of the tip of epiglottis which is the area which maximally increases in the lateral position and thus can be so helpful when lateral position can not be applied. Furthermore, the present study provides validation of the lateral positioning, often clinically applied, in sleeping or sedated children with congenital laryngomalacia. This comes in agreement with the conclusions made by Meier et al.¹⁴

A potential limitation of this study may be in the protocol of the arrangement of the positions where all subjects started the study in the supine position then was turned to the lateral position.

Each subject was used as his or her own control; it did not seem disadvantageous to perform the initial scan supine in every child so long that the depth of Ketamine/Midazolam 20:1 sedation was maintained at a constant level in both positions. Another limitation of this investigation is its inability to be extrapolated to other types of patient populations (e.g. age less than 2 yr, sleep apnea, and upper airway pathologies), other types of sedatives and other levels of sedation. Future studies are needed to accomplish this. Moreover, patients presenting for CT imaging of the head and neck were essentially predisposed to abnormalities in upper airway, and meticulous care was taken during subject selection to exclude subjects with probable airway abnormalities or muscle paresis secondary to a brain tumor. Nevertheless, subclinical abnormalities cannot be excluded.

In conclusion, the upper airway of a sedated, spontaneously breathing child widens in the lateral position. This widening was revealed at all non cartilaginous regions of the upper airway. The authors express their sincere gratefulness for Ahmed Mahmoud, MD, Department of Radiology, Cairo Radiology Centre and all the technicians for their expert aid in this clinical investigation. Our sincere gratitude also goes to Litman et al⁷ whose work inspired us a lot in the accomplishment of this study.

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