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ORIGINAL ARTICLE

Computed tomography virtual laryngoscopy: comparison between radiological and otolaryngological evaluations for laryngeal carcinoma

Bilgisayarlı tomografi sanal larengoskopi: Larenks kanserinde otolarengolojik muayene ile radyolojik değerlendirmenin karşılaştırılması

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Objectives: We evaluated the utility of computed tomography virtual laryngoscopy (CTVL) in identifying endolaryngeal lesions in laryngeal tumors.

Patients and Methods: Virtual laryngoscopic images were obtained from axial CT scans of 21 patients with known laryngeal carcinoma. Findings from rigid telescopic videolaryngoscopy (RTV) and CTVL images were evaluated and compared with reference to operative records.

Results: Lesions localized in the base of the tongue, pyriform sinus, aryepiglottic folds, and arytenoids were well visualized by both RTV and CTVL. The two techniques were not found effective in identifying lesions of the ventricular bands, ventricular cavities, and the anterior commissure. Virtual laryngoscopy was superior to RTV in the visualization of the subglottic area and vocal cords.

Conclusion: Virtual laryngoscopy is a noninvasive and reliable technique that provides visualization of endolaryngeal surfaces and tumor extension. It may be beneficial in staging larynx carcinoma and planning the most appropriate surgical procedure.

Key Words: Image processing, computer-assisted; laryngeal diseases/radiography; laryngoscopy; larynx/pathology/radiography; tomography, x-ray computed/methods.

Amaç: Larengeal tümörlü hastalarda, endolarengeal lezyon tayininde bilgisayarlı tomografi (BT) sanal larengoskopinin etkinliği araştırıldı.

Hastalar ve Yöntemler: Larengeal kanserli 21 hastada kontrastlı aksiyel BT kesitlerinden sanal larengoskopi görüntüleri elde edildi. Hastaların rijit teleskopik videolarengoskopik muayene bulguları ve sanal larengoskopi bulguları ameliyat kayıtlarıyla karşılaştırıldı.

Bulgular: Dil kökü, priform sinüs, ariepiglottik bant ve aritenoid seviyelerindeki lezyonlar her iki yöntemle de güvenilir bir şekilde gösterilebildi. Ventriküler bant, ventriküler kavite ve anterior komissür seviyelerindeki lezyonlar için her iki yöntem de güvenilir değildi. Subglottik bölge ve vokal kordlarda sanal larengoskopinin lezyon tayini daha güvenilir bulundu.

Sonuç: Sanal larengoskopi endolarengeal yüzeylerin görüntülenmesinde ve tümör yayılımının saptanmasında invaziv olmayan ve güvenilir bir yöntemdir. Larenks kanserli hastalarda cerrahi öncesi evreleme ve uygun cerrahi tekniğin seçiminde yararlı olabilir.

Anahtar Sözcükler: Görüntü işleme, bilgisayar destekli; larengeal hastalıklar/radyografi; larengoskopi; larenks/patoloji/radyografi; bilgisayarlı tomografi/yöntem.

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Proper assessment of laryngeal carcinoma, including precise determination of tumor location and stage is prerequisite to satisfactory treatment planing. All patients with laryngeal carcinoma should undergo diagnostic imaging unless they have early stage glottic cancers. Two major radiological modalities are used currently to image laryngeal carcinomas; computed tomography (CT) and magnetic resonance imaging (MRI). Other radiological examinations (plain X-ray, laryngogram, ultrasonography, and nuclear medicine) provide only limited information in specific clinical situations.[1] The imaging techniques provide detailed information about the tumor infiltration and demonstrate the relationship of tumor tissue to vital structures nearby.

Endoscopic examination with laryngoscopes allows careful mapping and delineation of endolaryngeal extension of the tumor. Tumor extension determines tumor stage, treatment options and ultimately influences prognosis. CT with virtual laryngoscopy (CTVL) is a new technique that allows visualization of endolaryngeal surfaces by multiplanar and threedimensional (3-D) visualization of air-tissue interfaces by reconstructing twodimensional (2-D) spiral CT data. These 3-D display provides an airway appearance similar to that obtained with laryngoscope.[2]

The goal of the present study was twofold: First we evaluatedthe ability and the clinical utility of CTVL to assess the endolaryngeal extent of tumor and second; we assesed whether there was any difference between CTVL and laryngoscopic examination to determine the endolaryngeal lesion map.

MATERIALS AND METHODS

From August 2001 to April 2003, twenty-one patients with carcinoma of the larynx were evaluated. All of them underwent complete head and neck examination and diagnostic evaluations including RTV, spiral CT and/or MRI. The study was conducted according to the ethical standards of our hospitals, which require informed consent from each patient. Four patients with laryngeal carcinoma who refused to have the surgery or having previous surgery were excluded from the study. Photographic images from RTV examinations were documented. The conventional computed tomographic images of the patients were used to construct virtual images. After completion of all diagnostic evaluations, staging of the carcinoma was obtained and surgical treatment was performed. We compared the RTV and CTVL images with surgical findings.

Video-recorded images from endoscopic examinations were reviewed by two otolaryngologists. A radiologist and an otolaryngologist independently, reviewed virtual laryngoscopic images. Both examinations were reviewed independently by two examiners with yielding one consensus. Videolaryngoscopy; a videographic documentation of endoscopic laryngeal examination using rigid telescopic videolaryngoscope and Karl Storz telecam single chip CCD camera was performed in all cases. The soft palate and posterior half of the tongue were topically anesthetized with 4% lidocaine. Starting from hypopharynx, visualized supraglottis, glottis, subglottis and tracheal region were examined and recorded. Representative photographs from these videos were printed on a Sony CVP G700 color video printer (Sony Corporation, Tokyo, Japan). Axial spiral CT imaging was performed on a Philips CT scanner (Netherlands); the scan was obtained from the skull base to the thoracic inlet, in a craniocaudad direction. Intravenous contrast (omnipaque 300 mg/ 20 ml, Sanofi Winthrop Pharmaceuticals, New York, NY) was given in all patients by power injector (2 ml/s, for a total of 150 ml). The following parameters were used: collimation thickness of 3 mm, pitch factor of 1.5, and reconstruction interval of 2 mm. The reconstructed axial spiral CT images were archived on digital tape and transferred to a Easy Vision workstation (Philips) for review and postprocessing. The three-dimensional virtual endoscopic images were created from the axial CT data by using navigation soft ware package on the workstation. The surface-shaded display of the lumen from inside, which then allows evaluation of the surface anatomy was obtained. A fly-through path of the lumen starting from oropharynx, caudad toward the tracheal opening was selected. Each subsites of the larynx and hypopharynx were bilaterally reviewed by 180 degree rotation. A stuff radiologist and an experienced otolaryngologist examined the images and defined the tumor sites and extension by differentiating normal tissue from tumor mass. Following defining the mass lesion, inferior aspect of the mass lesions were examined by back fly-through path towards the nasopharynx and a movie loop of the fly-through path of the lesion were created and archived. Selected axial and endoscopic images were filmed on hardcopy.

TABLE I

NUMBER OF PATIENTS WHO HAVE TUMOR EXTENSION ACCORDING TO RTV EXAMINATION, CTVL AND SURGICAL FINDINGS BY ANATOMICAL SUBSITES

Subsite	RTV			CTVL			Surgery Tumor (+)
	Visualized		Non-visualized	Visualized		Non-visualized	
	Tumor (-)	Tumor (+)		Tumor (-)	Tumor (+)		
Base of Tongue	20	1	0	20	1	0	1
Pyriform sinus	17	4	0	16	5	0	5
Epiglottis	9	12	0	10	11	0	11
Aryepiglottic fold	14	7	0	14	7	0	4
Arytenoids	15	6	0	14	7	0	8
Posterior commissure	15	6	0	13	8	0	8
Ventricular bands	4	15	2	3	17	1	19
Ventricular cavities	6	13	2	4	16	1	17
Vocal cords	6	12	3	5	16	0	13
Anterior commissure	7	6	8	7	13	1	12
Subglottis	10	1	10	15	6	0	6

RTV: Rigid telescopic video laryngoscopy; CTVL: Computed tomography virtual laryngoscopy.

In all patients, knowledge of the endolaryngeal surgical findings was compared with both diagnostic findings; RTV and CTVL using 11 subsite scala. Anatomical classification of the larynx according to IUCC (International Union Against Cancer Committee) was used for nine laryngeal subsites (epiglottis, aryepiglottic folds, arytenoids, posterior commissure, ventricular bands, ventricular cavities, vocal cords, anterior commissure and subglottis) and base of tongue and pyriform sinus were included in the examined sites.

For each subsite that is visualized in both RTV and CTVL imaging systems, if the tumor extension was correlating to the surgical findings; "true positive or negative involvement", if the tumor extension was not similar to the surgical findings; "false positive or negative involvement" was reported. If tumor extension in CTVL images or RTV examination could not be determined because of the tumor bulk or poor image quality in any subsite, it was reported as "nonvisualized". Sensitivity, specificity, negative predictive value (NPV) and positive predictive value (PPV) were calculated for both diagnostic-imaging methods in the determination of endolaryngeal lesion map. In this study, sensitivity (TP/[TP+FN], where TP=true-positive results and FN= false-negative results), is the percentage of subsites with surgically proven tumor extent that was correctly interpreted at imaging as positive for disease. Specificity (TN/[TN+FP], where TN=true-negative results and FP= false-positive results) is the number of subsites correctly interpreted as negative for disease at imaging, divided by the total number of subsite with no surgically proven tumor extension. The positive predictive value (PPV) (TP/[TP+FP]) is the percentage of subsites interpreted at imaging as positive for disease that had surgically proven tumor extension. The negative predictive value (NPV) (TN/[TN+FN]) is the percentage of subsites interpreted at imaging as negative for disease that had no surgically proven tumor extension. We used the Wilcoxon two-sample test for statistical analysis.

RESULTS

All of patients were men between 34 to 75 years of age with the mean age of 58 years. Twenty patients had pathologically documented squamous cell carcinoma and one patient had adenocarcinoma of the larynx. All patients had completed head and neck examination including RTV and CTVL. MRI was performed only on six cases. Patients, refusing further

TABLE II

THE SENSITIVITY AND SPECIFICITY VALUES FOR RTV AND CTVL IMAGING

Subsite	RTV		CTVL	
	Sensitivity	Specificity	Sensitivity	Specificity
Base of Tongue	1.00	1.00	1.00	1.00
Pyriform sinus	0.80	1.00	1.00	1.00
Epiglottis	1.00	0.90	1.00	1.00
Aryepiglottic fold	1.00	0.82	1.00	0.82
Arytenoids	0.75	1.00	0.88	1.00
Posterior commissure	0.75	1.00	0.88	0.92
Ventricular bands	0.80	1.00	0.87	1.00
Ventricular cavities	0.76	1.00	0.94	1.00
Vocal cords	0.77	0.57	1.00	0.63
Anterior commissure	0.45	0.50	0.92	0.57
Subglottis	0.17	1.00	1.00	1.00

RTV: Rigid telescopic video laryngoscopy; CTVL: Computed tomography virtual laryngoscopy.

diagnostic workup or surgery or having previous surgical exploration were excluded. Seven of 21 laryngeal tumors confined to supraglottis and two of these involved the hypopharynx. Fourteen of 21 laryngeal tumors were transglottic and two of these also invaded the hypopharynx. TNM staging of the tumors was obtained by evaluation of the axial CT images and MRI. There was no evidence of distant metastasis in the study group. The regional lymphadenopathy involvement was not present in 13 of them.

Numbers of patients who have endolaryngeal tumor extension according to CTVL and RTV examination were listed for all subsites with surgical outcomes (Table I). Following subsites were well visualized by both RTV and CTVL: base of tongue, pyriform sinus, epiglottis, aryepiglottic folds, arytenoids, posterior commissure. However, in some of cases some subsites couldn't be evaluated: ventricular bands, ventricular cavities, vocal cords, anterior commissure and subglottis by RTV and ventricular bands, ventric-

TABLE III

THE PPVS AND NPVS FOR RTV AND VL IMAGING

Subsite	RTV		CTVL	
	PPV	NPV	PPV	NPV
Base of Tongue	1.00	1.00	1.00	1.00
Pyriform sinus	1.00	0.94	1.00	1.00
Epiglottis	0.92	1.00	1.00	1.00
Aryepiglottic fold	0.57	1.00	0.57	1.00
Arytenoids	1.00	0.87	1.00	0.93
Posterior commissure	1.00	0.87	0.88	0.92
Ventricular bands	1.00	0.57	1.00	0.67
Ventricular cavities	1.00	0.33	1.00	0.75
Vocal cords	0.83	0.50	0.81	1.00
Anterior commissure	0.83	0.14	0.80	0.80
Subglottis	1.00	0.50	1.00	1.00

RTV: Rigid telescopic video laryngoscopy; CTVL: Computed tomography virtual laryngoscopy; PPV: Positive predictive value; NPV: Negative predictive value.

ular cavities, anterior commissure by CTVL. We had more difficulty in the visualization of the anterior commissure and subglottis by RTV than any other subsites. We evaluated whether RTV or CTVL examination could judge the endolaryngeal lesion map for carcinoma of the larynx. Table II presents the specificity and sensitivity values of RTV and CTVL for each subsites. In only one of the patients, there was involvement of the base of tongue, which was noted by both RTV and CTVL. CTVL examination revealed all the tumor involvements of pyriform sinus and epiglottis without any mistake, however in RTV one of the pyriform sinus and epiglottic area involvement was missed,and also there was one overdiagnosis at epiglottic area. Although four aryeppiglottic fold involvement were correctly seen, there were three false positive results in both diagnostic methods. Two surgically proven arytenoid involvements were missed by RTV and also one by CTVL. There were eight surgically proven posterior commissure involvements, two of them were missed by RTV and one by CTVL with associated one false positive result in CTVL. Ventricular bands and ventricular cavity could not be evaluated in two cases by RTV and one case by CTVL. Three of the visualized ventricular band lesions were missed by RTV and, two by CTVL. RTV failed to demonstrate the involvement of the ventricular bands in three cases and CTVL in two cases. There were four false negative results in the evaluation of ventricular cavity by RTV and one by CTVL. All of the vocal cords were visualized by CTVL and none of the involvement was missed, however, there were three overdiagnosis. Three of the vocal cord area couldn't be visualized by RTV and there is three false negative and two false positive results. Although it was well examined by CTVL, eight anterior commissure subsites and ten subglottic areas couldn't be visualized by RTV. Six of the anterior commissure and five of the subglottic involvement were missed by RTV and also one anterior commissure involvement by CTVL. One, three anterior commissure involvement was overdiagnosed by RTV and CTVL, respectively. Table III contains PPVs and NPVs for both diagnostic tools broken down by each subsite.

In the evaluation of all visualized subsites by RTV (206) there were 74 true positive, 99 true negative, 26 false negative and 7 false positive results. 228 subsites could be visualized by CTVL and there were 96 true positive, 116 true negative, 6 false negative and 10 false positive results. Overall sensitivity, specificity, PPV and NPV of RTV were 74%, 93%, 91% and 79%, respectively. Same statistical data of CTVL were 94%, 92%, 91% and 95%, respectively. There was statistically significant difference between the sensitivity and NPV of RTV and CTVL in the diagnostic evaluation of endolaryngeal lesion map ($p<0.05$).

DISCUSSION

Several organ systems have been studied previously using this technique, including gastrointestinal tract, genitourinary tract, upper and lower airways, otologic and neurological structures and blood vessels[3-10] In 1988 Zinreich et al.[8] reported the usefulness of 3D display in the head and neck region because of the ease of appreciation of 3D anatomy rather than mentally reconstructing a large number of contiguous axial images. Although CTVL could be performed with conventional CT, the airway appearance provided by spiral CT allows significantly improved quality and easier reconstruction for more applications, the entire neck can be scanned within a single breath-hold (approximately 30 second) and motion artifacts and misregistration can be minimized. Even if endoscopic examination can evaluate majority of the endolaryngeal anatomy,

Fig. 1 - *Subglottic tumor extension involving the right vocal cord from inferior perspective in computed tomography virtual laryngoscopy view (arrowhead). The inferior surface of left vocal cord is seen (arrow).*

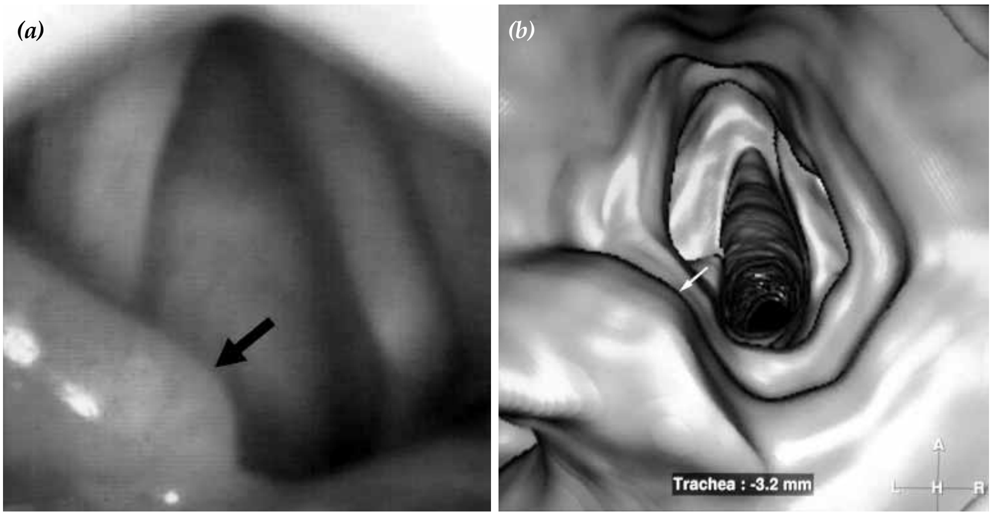

Fig. 2 - *Patient with supraglottic larynx carcinoma (arrows).* ***(a)*** *Rigid telescopic videolaryngoscopy image.* ***(b)*** *Computed tomography virtual laryngoscopy view from superior aspect.*

there are certain areas that are not optimally evaluated by laryngoscopy. These include the apices of the pyriform sinuses, the laryngeal ventricle and the subglottic region especially if there is a bulky tumor. RTV was not able to display some subsites in our patients, the majority of these were subglottic area, anterior commissure and also the vocal cords, ventricular cavity and ventricular bands couldn't be visualized in ten cases (10/21, 48%). In CTVL examination a ventricular cavity, a ventricular bands and an anterior commissure, total three subsites couldn't be evaluated in two cases (2/21, 9%) (Table I). There is statistically significant difference in the number of cases, which were completely evaluated and in the number of non-visualized subsites between CTVL and RTV examination.

The ability of CTVL and RTV to demonstrate laryngeal carcinoma was variable by laryngeal subsites. The sensitivity and the specificity of the base of tongue, pyriform sinus and epigglottis for RTV were high because of the ability of standard mirror examination. However, a pyriform sinus apical lesion was missed by RTV related to lower ability of RTV to show this location which is better delineated by CTVL because of the ability to visualize from different perspectives.[3] Gallivan et al.[7] mentioned the disabilities of the CTVL in the evaluation of pyriform sinus, tongue base, epiglottis due to apposition of two mucosal surfaces. However in our evaluation, the sensitivity and specificity of CTVL in the base of tongue, pyriform sinus and epiglottis were 100% and pathologic involvement were well demonstrated,

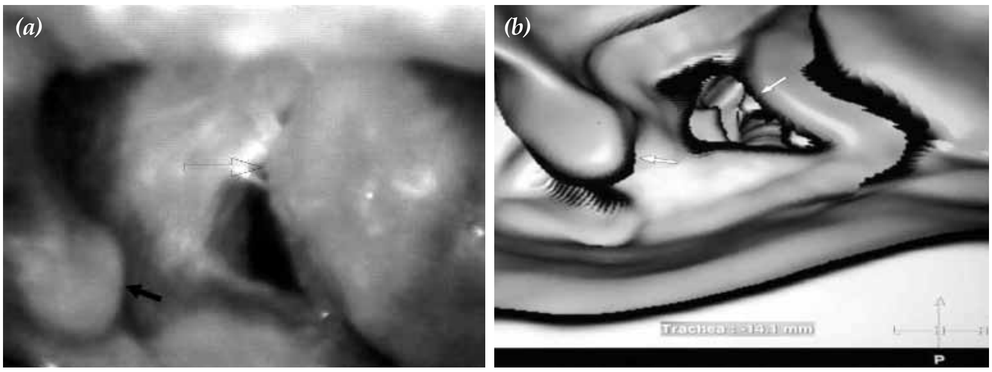

Fig. 3 - *Patient with gross transglottic laryngeal carcinoma involving right ventricular bant and left aryepiglottic fold (arrows). The mucosal surfaces and anatomic structures (anterior commissure) are not well visualized related to mass effect.* ***(a)*** *Rigid telescopic videolaryngoscopy image.* ***(b)*** *Virtual laryngoscopy image.*

probably due to advanced size of the laryngeal lesions. There is no statistically significant difference between the evaluation of the aryepiglottic folds, arytenoids, posterior commissure and ventricular bands involvement by RTV and CTVL, but CTVL sensitivity is minimally higher. In ventricular cavities and vocal cords CTVL had higher sensitivity than RTV representing better delineation of this area by producing sagittal cutaway views of the medial laryngeal surfaces and inferior views of the vocal cords, which displayed the ventricles and vocal cords clearly (Fig. 1). Walshe et al.[11] assessed the role of virtual laryngoscopy for vocal cord lesions in 10 patients and demonstrated that all lesions were correctly diagnosed by virtual laryngoscopy. Although anterior commissure and subglottic tumor extension was poorly seen with RTV or indirect laryngoscopy, VL was able to display subglottic anatomy with high sensitivity (Fig. 2a, b). Wang et al.[12] reported that CTVL could demonstrate the relationship between the tumor and vocal cords and anterior commissure by caudo-cranial approach. There was no statistically significant difference between the specificity of RTV and CTVL in all subsites.

When the mucosal surface was contacting each other related to the gross tumor mass, the quality of the imaging decreased. In the demonstration of late stage laryngeal carcinoma, the image quality of CTVL was low caused by inability to discern surface contour when two surfaces touching each other (Fig. 3, 4a, b). A gross tumor mass may decreased the image quality of the CTVL similar to RTV, with the exception of superior ability to visualize the subglottis from an inferior perspective (Fig. 1).[7,10] The subtle mucosal irregularities couldn't be appreciated by CTVL, limiting the sensitivity of this technique, especially for smaller tumors and mucosal T1 glottic tumors.[7] As most of our cases had advanced laryngeal carcinoma, this factor didn't impair the visualization of tumors.

Taking in account evaluation of the all subsites, there is statistically significant difference between the sensitivity of CTVL and RTV in the diagnosis of larynx carcinoma. In 62% of patients, all subsites were correctly evaluated. However this ratio was lower in RTV, 24%. Always CT scanning should be used in determining the lesion map of the larynx carcinoma except the early stage glottic cancer. CTVL cannot reveal transmural or extralaryngeal invasion and lymphatic spread of tumor as 2D-CT, can only provide contour definition, prominent mucosal irregularities of intraluminal anatomy. CTVL is a noninvasive, non-traumatic method, which can be used instead of invasive laryngoscopy technique when designating a tumor map.

RTV has great value in the diagnosis of laryngeal pathologies and documentation of abnormal condi-

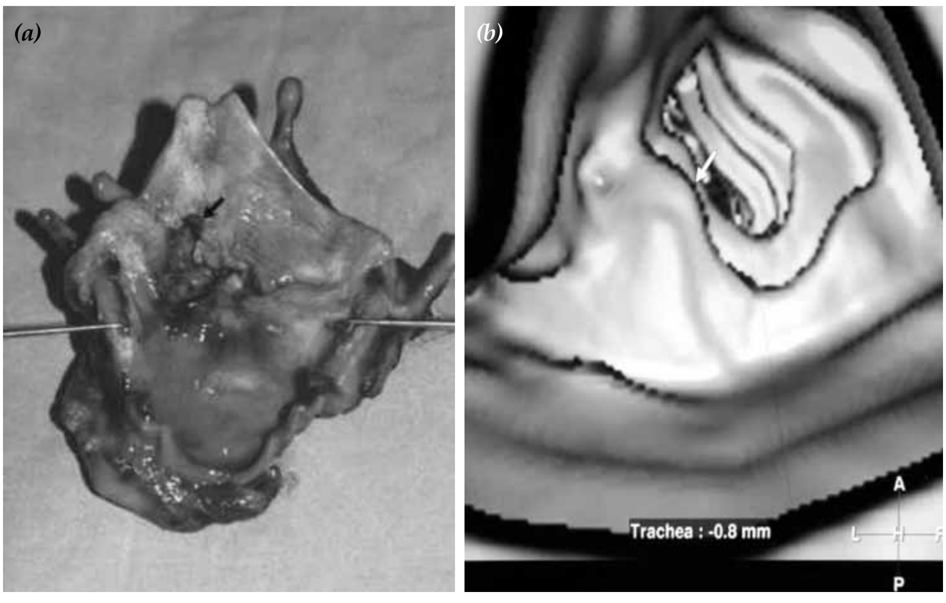

Fig. 4 - *The accuracy of CTVL was low related to endolaryngeal gross mass and surface contour irregularity. Patient with supraglottic tumor involvement (arrows).* ***(a)*** *Surgical specimen of tumor.* ***(b)*** *Virtual laryngoscopy image.*

tions. It is an invasive technique requiring local anestesia and may not be tolerated by children and some adults with hypersensitive gag reflexes. CTVL has ability to view the lesion from any angle with superior, inferior or oblique perspective without any lens angle distortion. It is excellent for evaluation of intraluminal lesion especially better than RTV in evaluation and follow up for lesions of the subglottic and anterior commissure region where there is significant narrowing that avoids safe passage of a scope through the obstruction.[5]

Although CTVL accurately delineates lesion map and provides excellent contour definition, its mucosal resolution is limited and it may escape mucosal and submucosal tumors. Other disadvantages of CTVL are the specialized hardware and software and also long time requirement for constructing and interpreting images which increases its cost. The image reconstruction took 1 hour at the beginning and decreased with the improving skill of examiner, which is similar to prior studies.[7,13]

It is important to mention that CTVL cannot be used for biopsy, unlike traditional laryngoscopy. However this technology can be used for intraprocedural guidance in the near future. CTVL provides additional intraluminal anatomic delineation in a manner more familiar to head and neck surgeons. It is not able to display extraluminal anatomy or the transmural extend of tumors or impaired vocal cord mobility.[14,15]

There are shortcomings of this study; one of them is limited number of study group. The other one is the stage characteristics of tumors, which doesn't represent all the stage of disease. None of the patients had early stage laryngeal carcinoma, in which CTVL is less reliable in tumor delineation. These characteristics of study group artificially improve the perceived sensitivity and specificity of CTVL over RTV.

In this prospective study, CTVL reveal better tumor map delineation, especially in the anterior commissure and subglottis. More subsites of the larynx could be visualized and evaluated in patients with advanced tumor by CTVL compared to RTV. Based on this limited experience, CTVL is a useful adjunctive examination technique that enhances diagnostic accuracy in the preoperative diagnosis of laryngeal carcinoma. Further studies with larger study group are required to better define the indication and useful application for virtual endoscopy in the term of complementing the standard axial CT. In future emerging technologies may offer improvement in the ability to define the intraluminal tumor delineation and aid in the development of new therapeutic methods.

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