KAPITEL 10 / *CHAPTER 10* [10]
THREE—DIMENSIONAL RECONSTRUCTION AND VIRTUAL ENDOSCOPY OF MALIGNANT TUMORS OF THE LARYNGOPHARYNX AND LARYNX

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Summary

Virtual multislice computed tomography (MSCT) endoscopy enables detailed identification of the anatomical and topographic characteristics of the larynx and laryngopharynx, precise localization and sizing of tumors, and assessment of surrounding bony, cartilaginous, and soft—tissue structures. This technique also allows evaluation of tissue density in both healthy and pathological areas, facilitating early detection of stage I and II disease. MSCT supports three—dimensional (Three—dimensional) organ reconstruction and virtual endoscopic visualization, providing a minimally invasive, comprehensive tool for diagnosis and preoperative planning in laryngeal and laryngopharyngeal malignancies.

Background

Cancers of the larynx and laryngopharynx constitute a major clinical and public health challenge, particularly in Eastern Europe, where they rank among the five most common malignancies of the neck. In Ukraine, incidence ranges from 6.5 to 8.5 cases per a hundred thousand individuals, a considerable burden given the vital functions of the body area, including phonation, airway protection, and swallowing.

Despite advances in oncology, late—stage diagnosis remains prevalent: up to 70% of patients present with stage III—IV disease, frequently with extensive local invasion and metastasis in 40—60% of cases. Delayed detection markedly reduces treatment efficacy and survival. This challenge is compounded by high diagnostic inaccuracy: clinical and morphological errors range from 25% to 69%, and conventional histopathology, long regarded as the gold standard, demonstrates effectiveness as low as 58%, exposing significant procedural limitations.

These epidemiological and diagnostic realities underscore the imperative to refine

[10]***Authors:*** *Sokolov Viktor, Rozhkovska Galyna, Dorofeeva Tamara, Tsvihovsky Viacheslav, Arbatska Anastasia*
Author's sheets: *0,41*

and optimize detection methods. Diagnostic strategies assume tailoring to tumor localization, volume, growth pattern, and histologic profile. The complex laryngopharyngeal anatomy and variable tumor behavior necessitate a multi—modal approach combining clinical evaluation, imaging, and histopathology.

Spiral computed tomography (SCT) with three—dimensional reconstruction and virtual endoscopy — offer promising solutions. SCT provides high—resolution, volumetric imaging, enabling detailed delineation of tumor extent and regional anatomy. Virtual endoscopy, a post—processing technique, permits non—invasive intra—luminal visualization, addressing limitations of fiber—optic laryngoscopy, especially for submucosal lesions and anatomically challenging regions such as the hypopharynx and anterior commissure.

Despite theoretical advantages, these technologies remain vastly underutilized due to a paucity of large—scale validation studies and standardized protocols. Studies have demonstrated solid diagnostic potential in heath care but unfortunately lack comprehensive data for adequate routine clinical adoption. Variability in imaging protocols, interpretative criteria, and integration with other modalities, which include magnetic resonance imaging (MRI) and positron emission tomography (PET), remain a barrier.

MRI, with superior soft tissue contrasting, complements computed tomography by defining cartilage invasion and soft tissue infiltration, both critical for surgical planning and prognostic assessment. Systematic assessment that combines MSCT and MRI enables objective diagnostics of tumor spread, informs individualized imaging strategies, and potentially reduces reliance on invasive procedures, enhancing both patient safety and comfort.

The objective of advancing methodological approaches to spiral CT acquisition and interpretation — including three—dimensional reconstruction and virtual endoscopy — is to improve early detection, reduce diagnostic error, and determine precise staging. These techniques provide high—resolution anatomical detail, allowing clinicians to differentiate tumor from inflammation, define invasion patterns, and plan a surgical or radiotherapeutic intervention with greater accuracy.

Virtual endoscopy simulates intra—luminal observations, revealing tumor morphology and surface irregularities inaccessible to conventional fiber—optic techniques, particularly in partially obstructed or anatomically complex airways. Combined with three—dimensional reconstruction, it offers a spatially highly accurate representation of tumor boundaries relative to surrounding structures. Integrating these imaging innovative modes addresses limitations of traditional diagnostics, including biopsy sampling errors and interpretative variability, improving the staging accuracy and enabling more tailored treatment strategies in critical care.

The complementary role of MRI remains critical: it characterizes soft tissue infiltration and cartilage involvement, informing prognosis and therapeutic planning. Combining MRI with CT—derived three—dimensional and virtual endoscopy provides a comprehensive anatomical and functional assessment, enhancing decision—making.

Nonetheless, clinical adoption remains inconsistent due to limited large—scale validation and lack of standardized workflows. Consensus highlights the need for further research to define optimal imaging techniques, diagnostic criteria, and integrative protocols combining three—dimensional reconstruction, virtual endoscopy, and conventional modalities [1—8].

In summary, three—dimensional reconstruction and virtual endoscopy represent pivotal innovations in the diagnosis and management of laryngeal and laryngopharyngeal malignancies. By enhancing visualization, improving staging accuracy, and integrating with complementary imaging modalities, they offer a multi—modal diagnostic framework capable of addressing current clinical limitations. Advancing these methodological approaches is a crucial frontier for improving early detection, guiding precise treatment, and ultimately enhancing patient outcomes in regions with high incidence and late—stage presentation.

Materials and Methods

A retrospective opportunistic comparative assessment of radiological diagnostic modalities for oncological ENT pathology was carried out using data from 315 patients treated at Odesa National Medical University. Patients were included based on

confirmed histopathological diagnoses of laryngeal or pharyngeal malignancy. Participants received a comprehensive physical exam with systematic clinical history documentation. The preliminary distribution of patients by tumor stage was as follows:

laryngeal cancer: T2N0M0 — 72 patients; T3N0M0 — 90 patients; T4N0M0 — 26 patients;

pharyngeal cancer: T2N0–3M0 — 50 patients; T3N0–3M0 — 50 patients; T4N0–3M0 — 27 patients.

Computed tomography (CT) imaging was performed using the NeuViz 64In multi—slice CT scanner (Neusoft Medical Systems Co., Ltd., China). The scanner was regularly calibrated with manufacturer phantoms, and routine quality control maintained image uniformity, noise levels, geometric accuracy, and Hounsfield unit consistency. These procedures standardized imaging and interpretation. Clinical status was established from combined clinical history and imaging data, providing a consistent, reliable measure. The scanner was coupled with the Vitrea—2 workstation (Vital Images Inc., USA), which enabled volumetric data reconstruction and advanced post—processing.

CT scans were acquired using standard head—and—neck protocols with slice thickness ranging from 0.5 to 1.0 mm to maximize spatial resolution. Intravenous contrast medium (non—ionic, iodine—based) was administered in 90—120 mL doses at a rate of 2—3 mL/s, followed by a saline flush to enhance vascular and tumor delineation. Scan parameters were optimized for head and neck structures, including adjustment of tube voltage (120 kVp) and current (150—250 mA), depending on patient size and region of interest.

Volumetric data sets were subjected to multiple reconstruction and rendering algorithms to enhance anatomical visualization and facilitate virtual endoscopy. Processing methods included:

1. Shaded Surface Display (SSD): Surface rendering was applied to highlight structural boundaries of bone, cartilage, and tumor margins.

2. Volume Rendering Technique (VRT): Narrow CT—number thresholds were applied to accentuate tissue contrast and differentiate soft tissue from cartilage,

mucosa, and infiltrative lesions.

3. Maximum Intensity Projection (MIP): This technique emphasized high—density structures, including ossified cartilage, calcifications, and contrast—enhanced vessels, aiding in the assessment of tumor vascularity and infiltration patterns.

4. Multi—Planar Volume Reformatting (MPR): Axial, coronal, and sagittal planes were reconstructed from volumetric data, allowing precise localization of tumor boundaries in three dimensions.

5. Navigator software with virtual endoscopy module: A flight—path program enabled simulation of endoscopic navigation through the laryngopharynx and larynx. The cursor could traverse severely narrowed luminal spaces, providing a non—invasive visualization of intra—luminal morphology, infiltration, or mass—like lesions.

Several protocol modifications were implemented to enhance clinical applicability and reproducibility:

•Gantry Tilt and Viewing Angles: The Vitrea—2 workstation permitted adjustment of gantry and viewing angles from 45° to 120°, improving visualization of anatomically complex regions such as the anterior commissure, piriform recess, and hypopharyngeal wall.

•Window Width and Level Settings: Customized windowing parameters were applied for bone (width 1700 HU, level 300 HU), cartilage (width 400 HU, level 50 HU), and soft tissues (width 400 HU, level 45 HU), optimizing contrast resolution for structural assessment.

•Flight Path Planning: Virtual endoscopic trajectories were manually adjusted to mimic clinical laryngoscopy, ensuring that areas of stenosis or suspected infiltration were fully evaluated.

•Slice Integration: Thousands of axial slices were automatically reconstructed into volumetric data sets, then manually verified for artifact reduction, motion correction, and alignment accuracy.

Radiologists were formally trained and certified in device operation, following standardized protocols to minimize inter—operator variability. All processed images

were independently reviewed by two experienced radiologists (with 10 and 15 years of head and neck imaging experience) blinded to histopathological results. Discrepancies were resolved by consensus. Each tumor was evaluated for:

- Extent of mucosal and submucosal involvement
- Cartilage invasion
- Bone destruction
- Regional lymph node involvement
- Presence of luminal narrowing or mass effect

The diagnostic yield of each imaging technique—SSD, VRT, MIP, MPR, and virtual endoscopy—was compared against histopathological findings, serving as the reference standard. The study also assessed the feasibility of integrating these protocols into routine clinical workflow, including total acquisition time, reconstruction time, and ease of navigation.

This methodology provided a comprehensive framework for comparative evaluation of advanced CT—based imaging techniques in onco—ENT pathology, emphasizing reproducibility, clinical relevance, and correlation with histopathology (fig. 1).

Results and Discussion

The four—slice multislice computed tomography (MSCT) protocol enabled precise determination of tumor localization, size, and extent, and facilitated revision of disease staging (fig. 2—6). Among patients initially staged as T2N0—3M0, 12 were upstaged to T3N0—3M0, while 16 patients initially staged as T3N0—3M0 were reclassified as T4N0—3M0. MSCT allowed multi—planar review, Three—dimensional reconstruction, and virtual endoscopy, providing clear visualization of destructive changes in laryngeal cartilages, evaluation of regional lymph nodes, and accurate assessment of tumor infiltration patterns. In most cases, imaging findings were corroborated by pathohistological examination of resected tumors, with macroscopic tumor structure closely corresponding to virtual endoscopic images.

Laryngopharyngeal Cancer. Early—stage detection remains challenging due to typical sites of origin and frequent submucosal spread. Primary tumors predominantly

arose in the piriform sinuses, posterior pharyngeal wall, and postcricoid region.

Endophytic tumors were identified by wall infiltration of the laryngopharynx and piriform sinuses, often extending to ligamentous structures.

Exophytic tumors presented as luminally protruding masses, frequently causing stenosis of lower airway segments.

Differentiation from concurrent inflammatory changes was enhanced using intravenous contrast (Visipaque—340, 70—100 mL). In the arterial phase, tumors demonstrated heterogeneous contrast uptake, with peripheral enhancement surrounding necrotic regions. Contrast also aided in lymph node evaluation: metastatic nodes appeared oval with moderate enhancement, whereas vascular structures were more rounded with minimal contrast accumulation.

Supraglottic Laryngeal Cancer. Characteristic findings included masses of the epiglottis extending to the aryepiglottic folds, piriform sinus involvement, and infiltration of the pre—epiglottic space.

Glottic (True Vocal Cord) Cancer. Imaging revealed increased vocal fold volume, infiltration into adjacent fatty tissues, and cartilage destruction. Virtual endoscopy demonstrated asymmetry and nodular surface irregularities corresponding to tumor infiltration.

Subglottic Laryngeal Cancer. This sub—type was distinguished by extensive spread to adjacent structures, including the thyroid gland and neck soft tissues, cartilage destruction, and airway stenosis.

Additional Findings. Spiral CT enabled reliable detection of regional and distant lymph node metastases, early identification of tumor recurrence, and objective evaluation of therapeutic response following chemotherapy or radiotherapy.

Diagnostic Accuracy and Clinical Implications. Three—dimensional reconstruction combined with virtual endoscopy significantly enhanced the diagnostic capabilities of MSCT. The technique allowed precise characterization of anatomical and topographic features, including tumor localization, shape, size, and volume; assessment of cartilage, bone, and soft—tissue involvement; evaluation of lymph node status; and monitoring of therapy effectiveness.

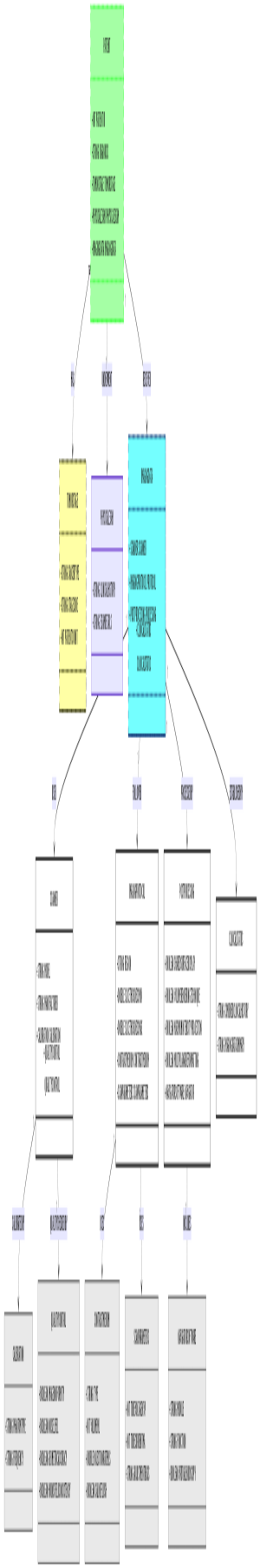

Fig. 1 - Experimental design.

Quantitatively, CT demonstrated a sensitivity of 98% for detecting tumor invasion into surrounding structures and a specificity of 82%. These findings suggest that three—dimensional reconstruction with virtual endoscopy may serve as a new reference standard for the assessment of laryngeal and laryngopharyngeal malignancies, offering a minimally invasive, highly accurate method to guide staging, treatment planning, and prognosis.

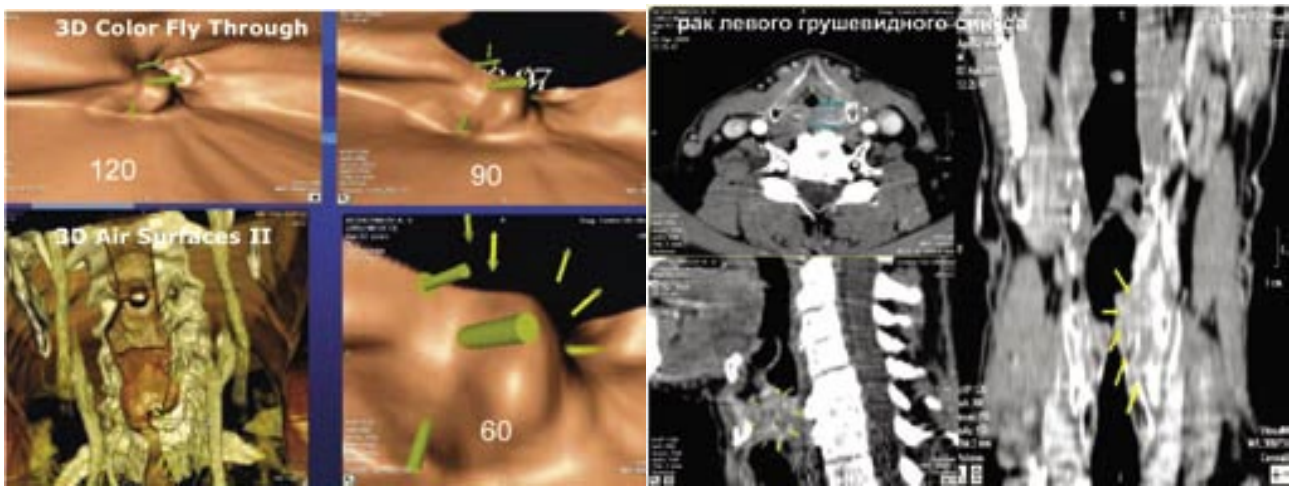

Fig. 2 - Multispiral CT: laryngopharyngeal cancer. Three—dimensional colour fly—through visualization.

Fig. 3 - Carcinoma of the supraglottic region of the larynx appearing as a nodular mass (see arrows)

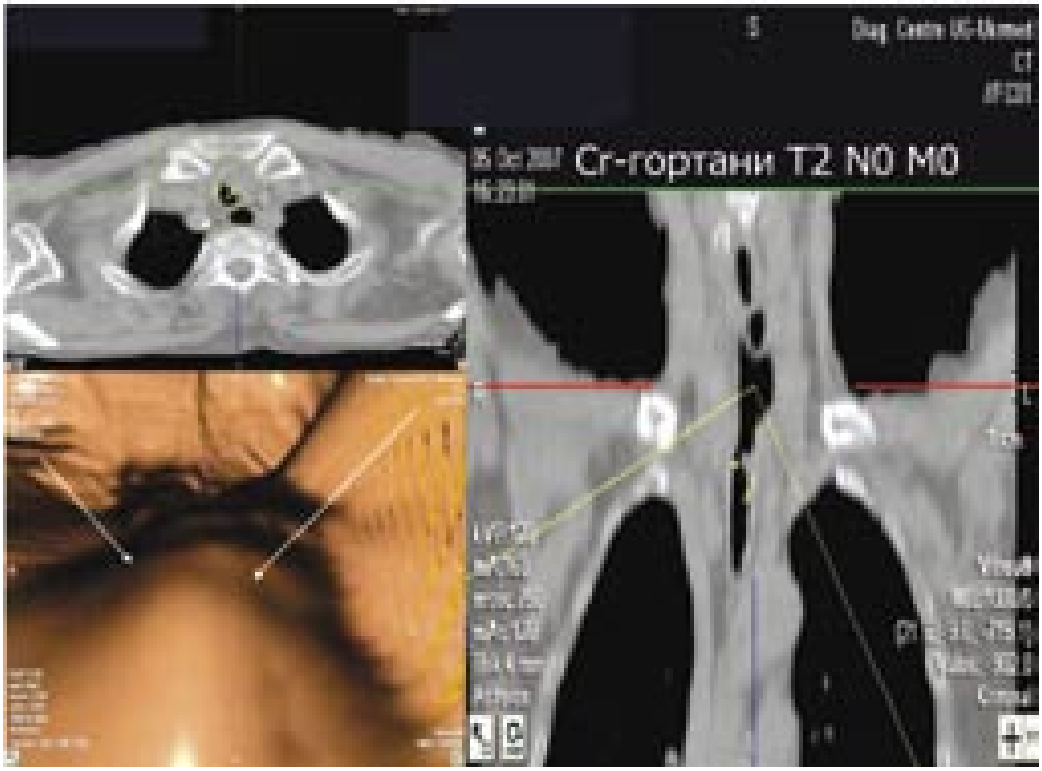

Fig. 4 - Carcinoma of the glottic region of the larynx compressing the laryngeal lumen (see arrows).

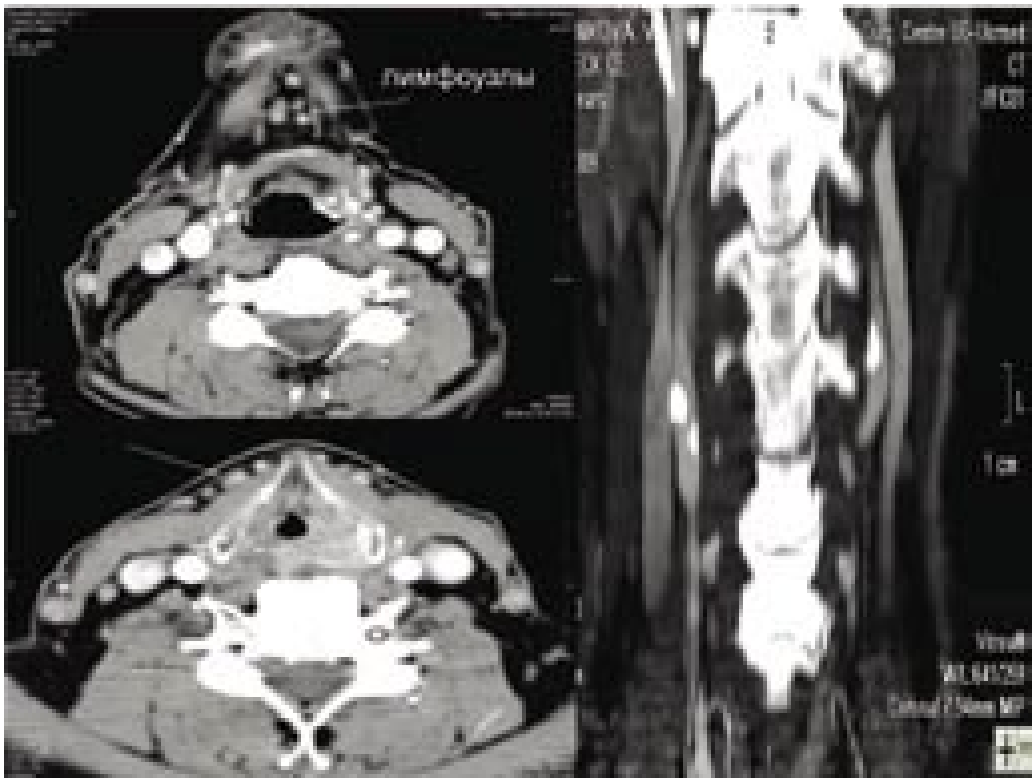

Fig. 5 - Distinctly visible lymph nodes in the submental region.

Fig. 6 - Subglottic stenosis caused by a nodular tumor (see arrows).

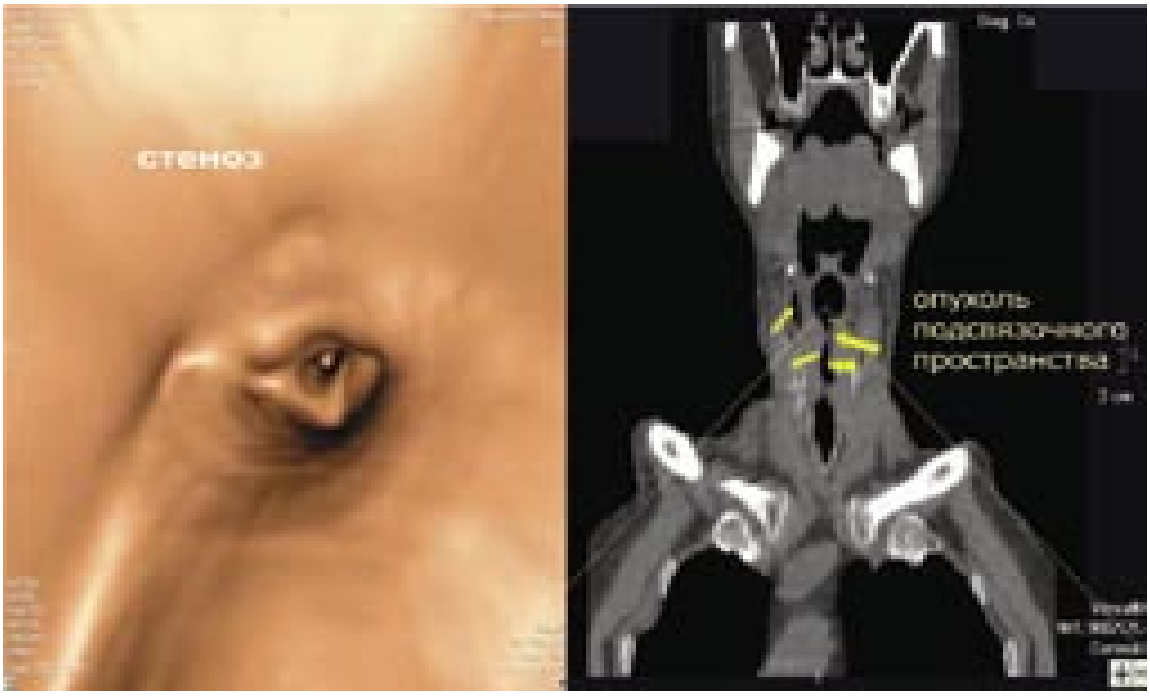

Fig. 7 - Subglottic stenosis caused by a nodular mass (see arrows)

Conclusions

The virtual laryngeal examination technique substantially enhances the diagnostic capabilities of MSCT. Three—dimensional—reconstruction combined with virtual endoscopy enables precise assessment of anatomical and topographic characteristics, tumor localization, shape, size, and volume, as well as evaluation of bony, cartilaginous, and soft—tissue structures. This approach also facilitates monitoring of therapeutic efficacy and determination of lymph node involvement.

In this cohort, MSCT demonstrated a sensitivity of 98% and a specificity of 82% for detecting tumor invasion into surrounding structures. These findings suggest that three—dimensional reconstruction with virtual endoscopy has the potential to become the reference standard for the evaluation of laryngeal and laryngopharyngeal malignancies, offering a minimally invasive, accurate, and comprehensive diagnostic tool.