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VIRTUAL ENDOSCOPY AND 3D VOLUME RENDERING IN THE MANAGEMENT OF MAXILLARY SINUS CANCER

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Summary

Objectives: To find out advantages and disadvantages of virtual endoscopy (VE) and 3D volume rendering (3DVR), helical CT data postprocessing methods, that might be useful in diagnostics and preoperative management of maxillary sinus cancer.

Methods: High-resolution helical CT scan (HRCT) of paranasal sinuses (slice thicknes 1.2 and 0.6 mm) was performed in a 41-year-old female with cancer of the right maxillary sinus. Siemens Somatom Emotion 16 scanner was used for data collection. Acquired images were stored in DICOM format. Ray casting fly-through algorithm was applied as well as 3D In-space volume rendering. The processing was done using a professional 3D Syngo CT 2006G software package.

Results: During the post-processing of data we made virtual sinusoscopy, virtual rhinoscopy and 3DVR. Image analysis was performed by one radiologist, one ENT specialist and one maxillofacial surgeon. Fly-through of virtual endocamera within the maxillary sinus and nasal cavity was manually driven. Using a mouse pointing device, we interactively changed the camera 3D position and focus. We also controlled the field of view of the camera. We found that inside the sinus, cancer was located on the floor and posterior wall. The surface involved by cancer was uneven, thickened and elevated in comparison to areas covered by healthy sinus mucosa. 3DVR showed cancer advance through the eroded posterior maxillary sinus wall towards the retromaxillary space. Reconstructed virtual images were comparable with those obtained by classical sinusoscopy. CT showed destruction of the posterior wall of the maxillary sinus and further tumor advance to the retromaxillary space. Parts of the hard palate were also involved. There were no cancer spread to other parts of the body.

Conclusion: VE accompanied with 3D In space analysis has several advantages in comparison to classical endoscopy. It is completely non-invasive. It is possible to repeat the same procedure hundreds of times, therefore it may be a valuable tool for training. Interactive control of all virtual camera parameters, including the field-of-view is possible. Endoscopic viewing as opposed to real endoscopy is not restricted to the spaces defined by inner surfaces. The viewer may penetrate the walls and see the extent of lesions within and beyond the wall. Finally, it has a potential to stage tumors by determining the location and the extent of transmural extension.

KEY WORDS: *high resolution computed tomography, virtual endoscopy, 3D volume rendering, maxillary sinus cancer*

VIRTALNA ENDOSKOPIJA I TRODIMENZIONALNO VOLUMNO RENDERIRANJE U OBRADI BOLESNIKA S KARCINOMOM MAKSILARNOG SINUSA

Sažetak

Ciljevi rada: Demonstracija prednosti i nedostataka virtualne endoskopije (VE) i trodimenzionalnog volumnog renderiranja (3DVR), tehnika postprocesiranja podataka dobivenih spiralnom kompjutoriziranom tomografijom visoke razlučivosti, koje mogu biti korisne u dijagnostici i preoperativnoj obradi bolesnika s karcinomom maksilarnog sinusa.

Metode rada: Spiralni CT visoke razlučivosti (HRCT) paranazalnih sinusa (debljine slojeva 1,2 i 0,6 mm) napravljen je u četrdesetjednogodišnje bolesnice s karcinomom desnog maksilarnog sinusa. Siemens Somatom Emotion 16 CT uređaj je primijenjen za prikupljanje podataka. Dobivene serije slika pohranjene su u DICOM formatu na elektroničkom računalu. U postprocesiranju primijenjen je algoritam "ray-casting" za virtualnu endoskopiju kao i trodimenzionalno "in-space" volu-

mno renderiranje za 3D prikaz promatranog dijela tijela. Obrada podataka napravljena je s pomoću 3D Syngo CT 2006G specijaliziranog programskog paketa.

Rezultati: Tijekom postprocesiranja podataka napravili smo virtualnu sinusoskopiju, virtualnu rinoskopiju i 3DVR. Analizu dobivenih slikovnih prikaza napravili su po jedan radiolog, otorinolaringolog i maksilofacijalni kirurg. Let (fly-through) virtualne endokamere unutar maksilarnog sinusa i nosne šupljine je ručno vođen radi bolje preciznosti. Uz pomoć računalnog miša interaktivno je mijenjan položaj, fokus i pogled kamere u prostoru. Također smo na isti način kontrolirali širinu vidnog polja kamere. Unutar desnog maksilarnog sinusa karcinom bio je smješten na dnu sinusa i na stražnjoj stijenci. Površina zahvaćena tumorom bila je neravna, zadebljana ii izdignuta iznad površine zdrave sluznice sinusa. 3DVR prikaz pokazao je napredovanje karcinoma kroz erodiranu stražnju stijenku maksilarnog sinusa prema retromaksilarnom prostoru. Dijelovi tvrdog nepca također su zahvaćeni tumorom. Nije dokazano širenje tumora u ostale dijelove tijela. Rekonstruirani VE i 3DVR slikovni prikazi slični su onima koji se dobiju prilikom klasične endoskopije sinusa.

Zaključak: VE zajedno sa 3DVR ima nekoliko prednosti u odnosu na klasičnu endoskopiju. Potpuno je neinvazivna. Moguće je ponavljati istu proceduru nebrojeno puta bez rizika ili neugodnosti za bolesnika, zbog toga ova tehnika predstavlja vrijedan alat za edukaciju. Moguća je interaktivna kontrola svih parametara virtualne endokamere uključujući i širinu vidnog polja. Za razliku od klasične endoskopije slikovni prikazi nisu ograničeni na prostore definirane stijenkama tjelesnih šupljina. Kliničar može endokameru pomicati kroz stijenke sinusa ili drugih šupljina te pratiti širenje lezije kroz stijenke u okolne anatomske strukture. VE i 3DVR pomažu prilikom staginga tumora svojom mogućnošću određivanja lokacije i opsega transmuralnog širenja tumora..

KLJUČNE RIJEČI: *kompjutorizirana tomografija visoke razlučivosti, virtualna endoskopija, 3D volumno renderiranje, karcinom maksilarnog sinusa*

INTRODUCTION

Cancers of the nasal cavity and paranasal sinuses are rare, comprising less than one percent of all human malignancies and only three percent of those arising in the head and neck (1). Males are affected two to three times more often than females, and most patients are in their fifth to seventh decade at the time of diagnosis. Cancers of the maxillary sinus are the most common of the paranasal sinus cancers (80%). Tumors of the ethmoid sinuses are less common (19-20%), and tumors of the sphenoid and frontal sinuses are rare (<1%) (2-6).

The majority of tumors of the paranasal sinuses present with advanced disease, and cure rates are generally poor (50%). Squamous cell carcinoma is the most frequent type of malignant tumor in the nose and paranasal sinuses (70%-80%). Papillomas are distinct entities that may undergo malignant degeneration. The cancers grow within the bony confines of the sinuses and are often asymptomatic until they erode and invade adjacent structures (7-9). Mucoepidermoid carcinoma (MEC) rarely occurs in the sinonasal tract. Both high-grade and low-grade tumors have been reported. The prognosis is better for low-grade tumors. Overall mortality is low when the tumor is managed as the more common squamous cell carcinoma of the sinonasal tract. MEC tend to present very late in their disease course with 25% of patients having distant metastases at the time of diagnosis. Complete resection of these tumors is difficult due to the propensity for widespread local invasion. Combined treatment with surgery and X-ray therapy offer the best chance of cure for most patients. It requires careful preoperative planning, including CT and MRI imaging. The choice of surgical approach depends upon tumor extension into adjacent structures.

The high mortality rate and poor prognosis associated with paranasal sinus tumors is related to late diagnosis secondary to the early symptomatic latency of these lesions. Most lesions are at an advanced stage at the time of definitive diagnosis. Some data indicate that various industrial exposures may be related to cancer of the paranasal sinuses and nasal cavity. The risk of a second primary head and neck tumor is considerably increased.

One reason for these poor outcomes is the close anatomic proximity of the nasal cavity and paranasal sinuses to vital structures such as the skull base, brain, orbit, and carotid artery. This complex location makes complete surgical resection of sinonasal tumors a challenging and sometimes impossible task.

The 5-year and 10-year actuarial survival rates for all maxillary sinus cancer patients were

34% and 31%, respectively (10). Combined surgical and radiation treatment to the primary tumor yielded higher survival and local control than radiotherapy alone. Other significant prognostic factors for survival were patient age, gender, and lymph node (N) classification. Prolonged overall radiation time was associated with poorer survival and local control. Late severe toxicity from the treatment of these tumors was a significant problem in long-term survivors. (10). The primary cause of death from paranasal sinus malignancies is failure of local control.

In recent years the widespread use of systematic nasal endoscopy and high resolution computed tomography have contributed to earlier diagnosis of paranasal sinus cancer. However, the very large quantity of data now generated in MSCT examinations can be unwieldy to manipulate and view.

Postprocessing of helical CT datasets acquired from patients with benign or malignant lesions of paranasal sinuses offers useful additional help in diagnostics and preoperative management.

Virtual Endoscopy (VE) is a technique to explore hollow organs and anatomical cavities using 3D medical imaging and computer graphics. VE allows simulated three-dimensional (3-D) visualization of anatomical structures by computerized reconstruction of radiological images. VE turns out to be a promising technique to improve, or even in some procedures substitute, real endoscopy (11,12).

3D Volume rendering is a flexible and accurate 3D imaging technique that can help clinicians to more effectively understand the large volumes of data generated by modern helical CT scanners (13). Recent advances in computer technologies have made 3DVR a practical, interactive technique that allows processing and display to occur in real time.

VE and 3DVR can clearly display the anatomic structure of the paranasal sinuses, nasopharyngeal cavity and upper respiratory tract, revealing damage to the sinus wall caused by a tumor. VE is a method which produces very clear images. It is reliable to provide detailed information for optimal operative planning (13,14).

3DVR has made significant contributions in surgical planning. A majority of surgical procedures involve a complex 3D relationship between the affected tissue and adjacent anatomic structures (13).

Our goal was to find out advantages and disadvantages of virtual

endoscopy and 3D volume rendering in standard clinical practice and to evaluate benefits or shortcomings of these methods.

METHODS

Three-dimensional information obtained from high resolution helical computed tomographic (HRCT) data was used to explore and evaluate the nasal cavity and paranasal sinuses and surrounding structures by virtual endoscopy and 3DVR in a 41-year-old female with cancer of the right maxillary sinus. Thin-section helical CT of the nasal cavity and paranasal sinuses was performed on a Siemens Somatom Emotion 16 scanner (slice thicknes 1.2 and 0.6 mm). Acquired images were stored in the DICOM format. Ray-casting fly-through algorithm was applied as well as 3D in-space volume rendering. Processing was done using the professional 3D Syngo CT 2006G software package.

Additional views not normally accessible by conventional endoscopy were generated.

RESULTS

A 41-year-old female was referred to ENT, oral and maxillofacial surgery due to dental problems, headache and nonspecific symptoms from the nose and paranasal sinuses. There was no professional exposure to known agents associated with paranasal sinus cancer. She underwent dental extraction as treatment for her pain before few months, which resulted in an oroantral fistula and lead to further management and the definitive diagnosis. Due to persistent pain after the dental extraction, the oral surgeon made initial diagnosis of radix relictae 24 and performed alveotomy. The ENT and maxillofacial surgeon referred her to high-resolution helical CT scan of the paranasal sinuses. HRCT (slice thickness 1.2 and 0.6 mm) was performed and finally revealed cancer of the right maxillary sinus that eroded the sinus posterior wall and floor, part of the hard palate and mi-

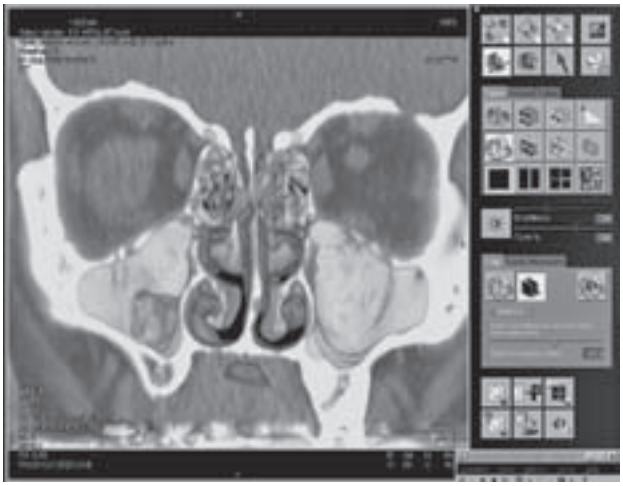

Figure 1. 3DVR showed interior surface of both maxillary sinuses in the 41-year old female with right maxillary sinus cancer. Malignancy of the maxillary sinus posterior wall and floor was clearly revealed as well as its relationship to surrounding anatomical structures.

Figure 2. Axial CT image showed tumor extension beyond the maxillary sinus into the retromaxillary region. Posterior and medial walls were eroded. Soft tissue edema was found behind the inferior nasal turbinate posterior end.

nor wing of the sphenoid bone. Cancer was presented as T4N0M0. Fly-through of virtual endocamera within the maxillary sinus and nasal cavity was manually driven. Using a mouse pointing device, we interactively changed the camera 3D position and focus. We also controlled the field of view of the camera. We found that inside the sinus cancer was located mostly on the floor and poste-

Figure 3. Workstation review allows the use of clip planes and sliding slab reformat techniques, enabling the radiologist or head and neck surgeon to temporarily select a portion of the imaging data and remove overlying soft tissue, and to move through the data volume in real time. The frontal clip plane was moved towards the posterior maxillary sinus wall. The eroded maxillary sinus floor, cancer mass within the sinus and defect of the right alveolar arch were shown.

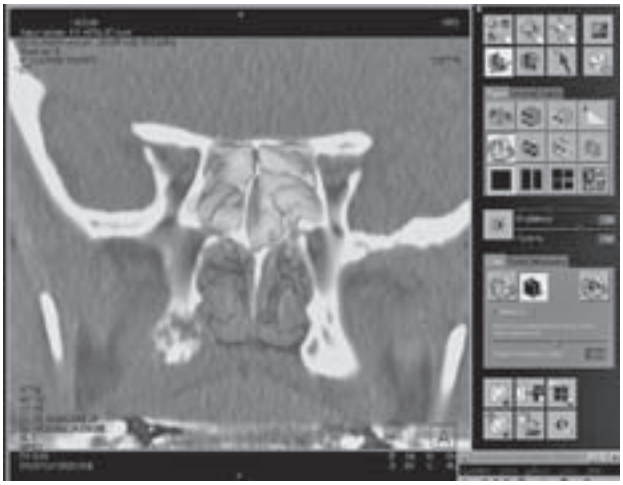

Figure 4. Further advance of the frontal clip plane in posterior direction revealed the eroded minor sfenoid wing at the right side in close proximity to the enlarged posterior end of the inferior nasal turbinate at the same side. Sphenoid sinuses presented normal appearance.

rior wall. The surface involved by cancer was uneven, thickened and elevated in comparison to areas covered by healthy sinus mucosa.

Axial HRCT images, as well as sagital reconstructions and 3DVR showed cancer advance through the eroded posterior maxillary sinus wall towards the retromaxillary space.

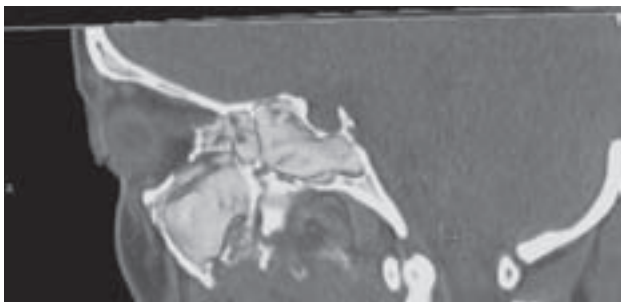

Figure 5. 3DVR reconstruction with the sagital clip plane applied. Right sphenoid and maxillary sinus cavities were presented, as well as cancer mass and eroded bone.

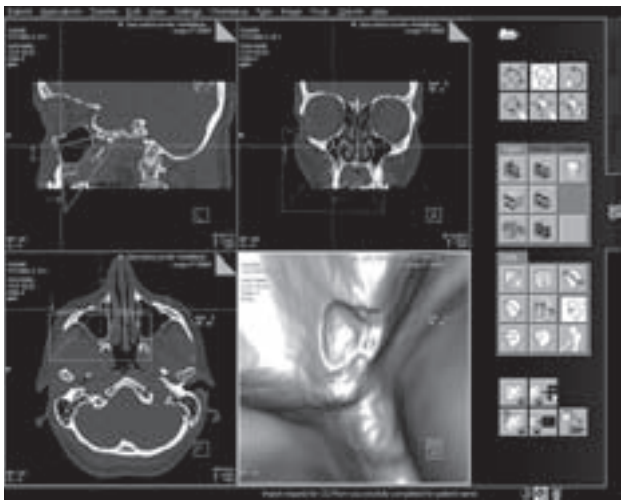

Figure 6. Working environment for virtual endoscopy was divided in four windows. Virtual endocamera location was shown in three main coordinate planes, whereas virtual endocamera view was presented in the fourth window. Endocamera was directed towards the angle where posterior, medial and inferior sinus wall contact each other. VE revealed the tumor location and its relationship to surrounding structures.

VE and 3DVR processing were performed by a multidisciplinary team – one radiologist, one ENT and maxillofacial surgeon.

After preoperative management, our patient underwent partial maxillectomy with preservation of the orbit at Clinic for Maxillofacial Surgery. Postoperative irradiation therapy was applied.

DISCUSSION

The advancement of high resolution computed tomography with thin sections and intravenous contrast has greatly improved the clinician's ability to diagnose paranasal sinus lesions, allowing

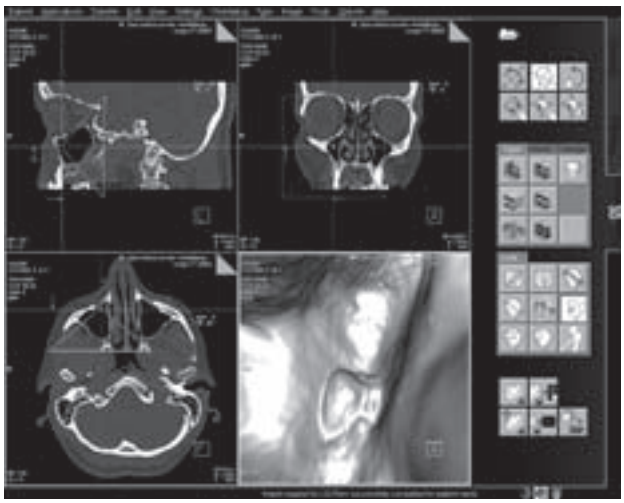

Figure 7. Virtual endocamera view was moved upwards and directed towards the posterior sinus wall.

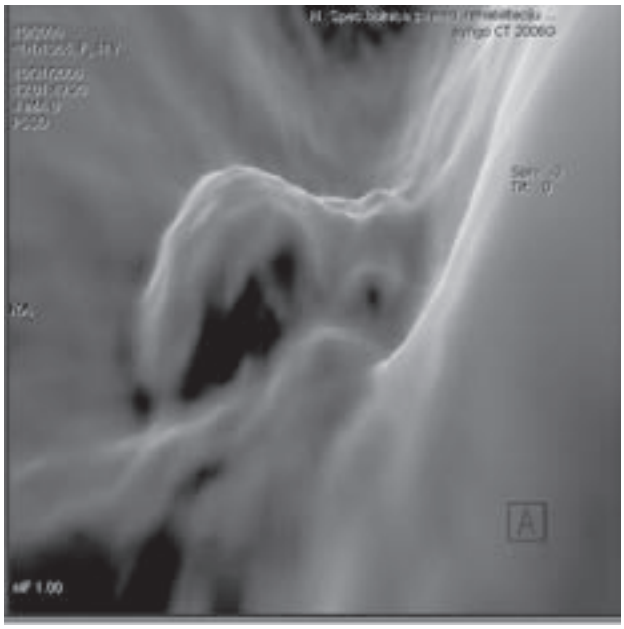

Figure 8. An enlarged and additionaly postprocessed image showed an endocamera close view to tumor mass in the sinus cavity and its relationship to surrounding structures.

for earlier detection and more accurate staging. Extension of the tumor into the intracranial cavity, orbit, pterygomaxillary fossa, or into the soft tissues of the face is easily demonstrated on HRCT (13,14). In addition, bony erosion is well illustrated by HRCT and 3DVR. In spite of these properties, it is not always possible to distinguish tumor from mucosal edema secondary to sinus obstruction by the lesion on CT. In addition, CT cannot

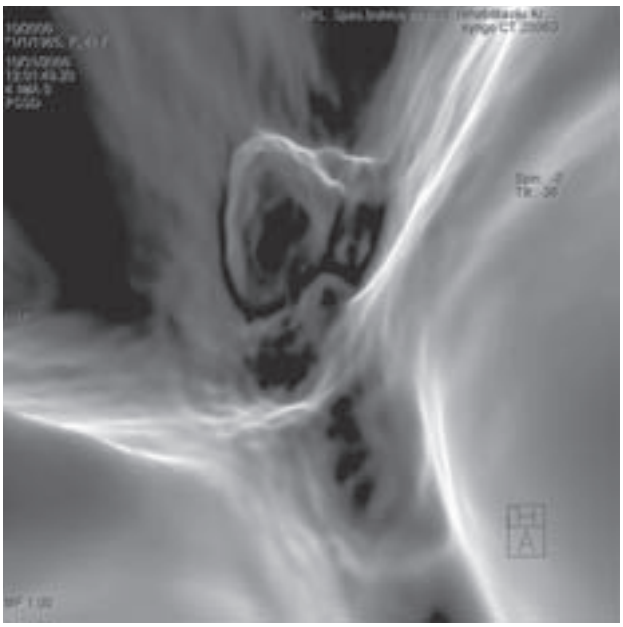

Figure 9. Virtual endocamera position was changed, and moved upwards and in posterior direction. The image was additionally postprocessed.

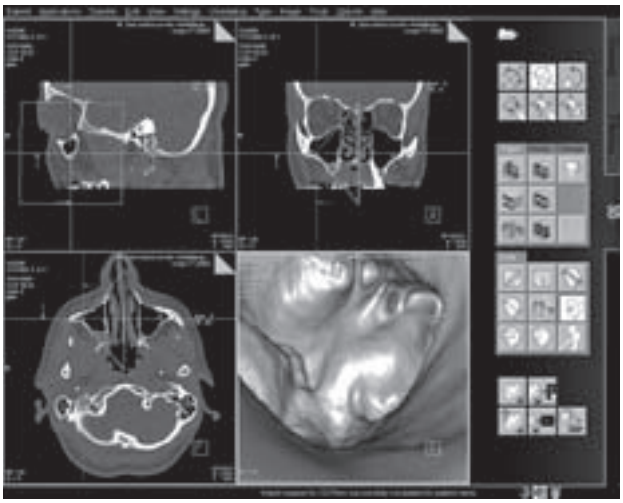

Figure 10. Virtual endocamera view was directed towards the medial maxillary sinus wall. Tumor mass and mucosa swelling was presented on the posterior sinus wall, posterior part of the sinus floor as well as portion of the posteroinferior medial sinus wall.

always clearly determine whether the tumor has invaded the periorbita, and that is important for planning needs for orbital exenteration (3-11).

Using virtual endoscopy and 3DVR different goals can be achieved. These goals range from teaching, diagnosis, intervention planning: providing insight into the potentially complicated

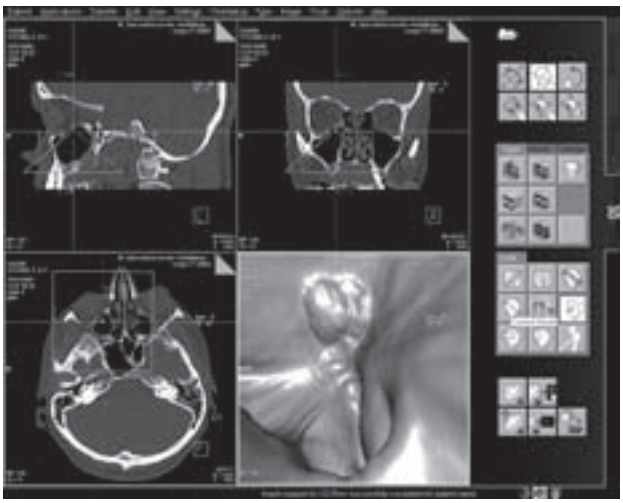

Figure 11. Virtual endocamera was situated near to the maxillary sinus roof and its view directed downwards.

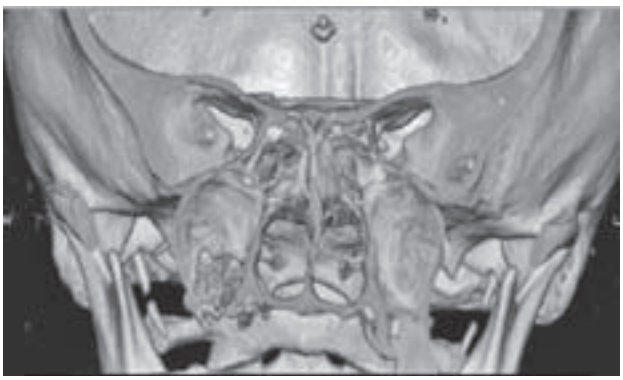

Figure 12. 3DVR reconstruction showed the extent of bone destruction in the right maxillary sinus. The frontal clip plane was applied and some structures were removed.

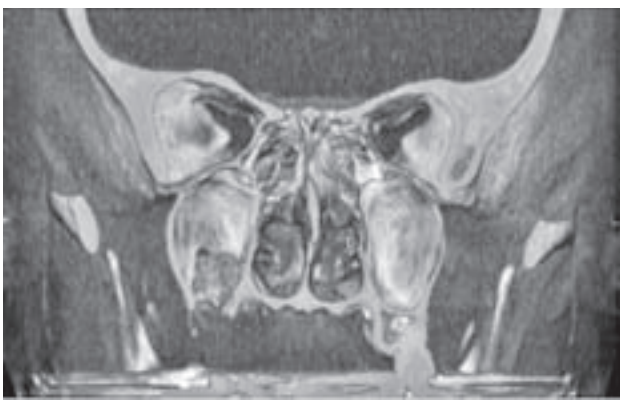

Figure 13. Special 3DVR reconstruction using the frontal clip plane showed vascularization of the tumor mass within the maxillary sinus.

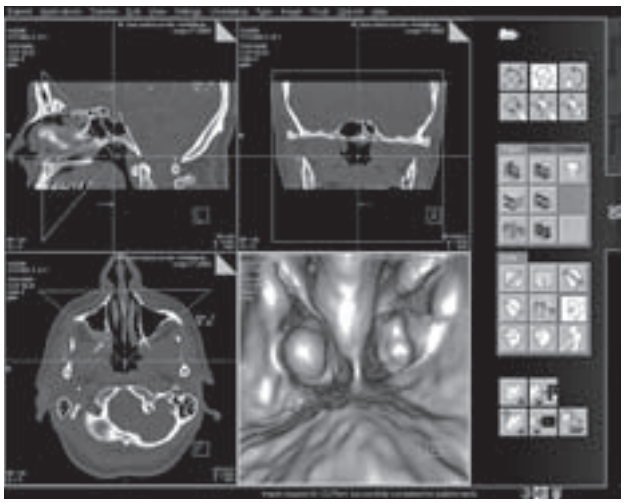

Figure 14. Posterior virtual rhinoscopy. Virtual endocamera was situated in the epipharynx and its view directed towards the nasal septum and turbinates. The enlarged and uneven posterior end of right inferior nasal turbinate was found.

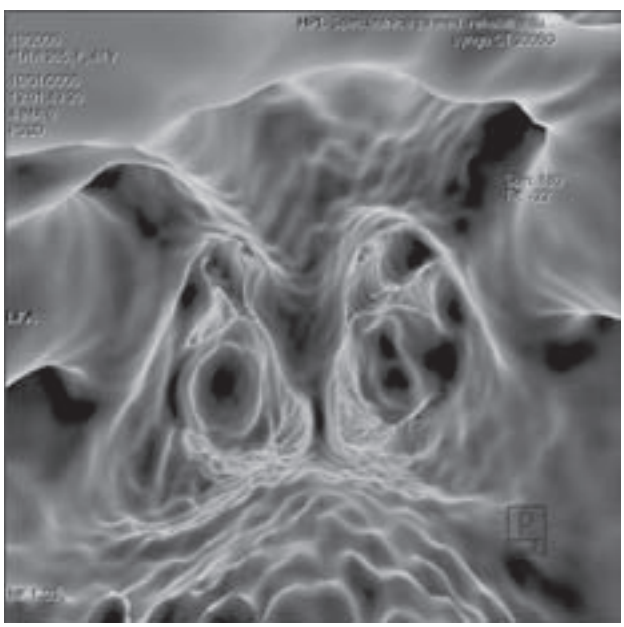

Figure 15. Postprocessed 3DVR image of posterior rhinoscopy. The posterior end of the inferior nasal turbinate was enlarged and deformed due to cancer invasion.

and non-standard anatomy of the patients intraoperative navigation, etc (11,12,15,16).

Virtual endoscopy also gives the added benefits of the ability to assess the transmural extent of disease This technology may well provide clinical benefit in preoperative planning, staging, and intraprocedural guidance for head and neck disease and merits further study (12,14,15).

The role of 3D volume rendering in radiology continues to grow rapidly. Areas that have received a great deal of attention to date include evaluation of musculoskeletal trauma, vascular imaging, and numerous applications in oncology. Since the inception of 3D reconstruction of CT data, applications in skeletal anatomy have provided an opportunity for demonstrating the efficacy of the new techniques (13).

Workstation review also allows the use of clip planes and sliding slab reformat techniques, enabling the radiologist to temporarily select a portion of the imaging data and remove overlying soft tissue, and to move through the data volume in real time (13,16). Multidisciplinary approach in the management of maxillary sinus cancer patients is required in order to achieve the best results (17).

CONCLUSION

Selectively applying 3DVR and VE may be very helpful in localizing and identifying cancer of paranasal sinuses, and allowing the head and neck surgeon a visuospatial appreciation of the surgical approach. The acquisition of high-quality diagnostic datasets remains the first goal in the HRCT, 3DVR and VE management of maxillary sinus cancer. A failure at this stage affects all subsequent image manipulation and interpretation. This requires attention to detail and continuous review of image quality.

VE and 3DVR have several advantages in comparison to classical endoscopy. VE and 3DVR are completely non-invasive. It is possible to repeat the same procedure hundreds of times, and therefore it may be a valuable tool for training. Interactive control of all virtual camera parameters, including the field-of-view is possible. Endoscopic viewing as opposed to real endoscopy is not restricted to the spaces defined by inner surfaces. The viewer may penetrate the walls and see the extent of lesions within and beyond the wall. Finally, it has a potential to stage tumors by determining the location and the extent of transmural extension.

REFERENCES

1. Grant RN, Silverberg E. Cancer Statistics 1970. American Cancer Society, New York, 1970.
2. Lewis JS, Castro EB. Cancer of the nasal cavity and paranasal sinuses. J Laryngol Otol 1972; 86: 255.

3. Spiro JD, Soo KC, Spiro RH. Squamous carcinoma of the nasal cavity and paranasal sinuses. Am J Surg 1989; 158: 328.
4. Frazell E, Lewis JS. Cancer of the nasal cavity and accessory sinuses: a report on the management of 416 patients. Cancer 1963; 16:1293.
5. Tabb HG, Barranco SJ. Cancer of the maxillary sinus. Laryngoscope 1971; 81: 818.
6. Jackson RT, Fitzhugh GS, Constable WC. Malignant neoplasms of the nasal cavities and paranasal sinuses (a retrospective study). Laryngoscope 1977; 87: 726.
7. Mendenhall WM, Riggs CE Jr, Cassisi NJ: Treatment of head and neck cancers. In: DeVita VT Jr, Hellman S, Rosenberg SA, eds.: Cancer: Principles and Practice of Oncology. 7th ed. Philadelphia, Pa: Lippincott Williams & Wilkins, 2005, pp 662-732.
8. Laramore GE, ed.: Radiation Therapy of Head and Neck Cancer. Berlin: Springer-Verlag, 1989.
9. Thawley SE, Panje WR, Batsakis JG, et al., eds.: Comprehensive Management of Head and Neck Tumors. 2nd ed. Philadelphia, Pa: WB Saunders, 1999.
10. Le QT, Fu KK, Kaplan M, Terris DJ, Fee WE, Goffinet DR. Treatment of maxillary sinus carcinoma: a comparison of the 1997 and 1977 American Joint Committee on cancer staging systems. Cancer. 1999;86(9): 1700-11.
11. Robb, R.A., C. Barillot, Interactive display and analysis of 3-D medical images, IEEE Transactions on Medical Imaging 1989; 8: 217-26.
12. Rogalla,P., Virtual Endoscopy: An Application Snapshot. Medica Mundi 1999; 43:17-23.
13. Calhoun PS, Kuszyk BS, Heath DG, Carley JC, Fishman EK. Three-dimensional volume rendering of spiral CT data: Theory and method. RadioGraphics 1999; 19: 745–64.
14. Tao X, Zhu F, Chen W, Zhu S. The application of virtual endoscopy with computed tomography in maxillofacial surgery, Chin Med J (Engl). 2003;116(5): 679-81.
15. Indrajit IK, Souza JD, Pant R, Hande PC. Virtual scopy with multidetector CT. MJAFI 2006; 62: 60-3.
16. Rubin G, Beaulieu C, Argiro V, Ringl H, Norbash A, Feller J, Dake M, Jeffrey R, Napel S. Perspective volume rendering of CT and MR images: Application for endoscopic imaging. Radiology 1994; 199: 321–30.
17. Sakai S et al. Multidisciplinary treatment of maxillary sinus carcinoma, Cancer 1983; 52:1360.

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