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VIRTUAL COLONOSCOPY AND 3D RECONSTRUCTION IN COLORECTAL CANCER PATIENTS

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Summary

Introduction: Virtual endoscopy of the colon or virtual colonoscopy (VC) is a technique for postprocessing high resolution helical CT datasets. 3D surface rendering volume reconstruction that simulates endoscopic views of the inner surface of the colon was performed in real time by means of computer generated ray casting. VC may be performed together with 3D volume rendering (3DVR). VC can be applied in teaching, diagnostics, intervention planning or intraoperative navigation and as a non-invasive technique it is particularly useful when the patient cannot tolerate classical fiberoptic endoscopy.

Objectives: To implement VC as a new technique of high resolution helical CT data postprocessing in screening, preoperative diagnostics and management and to discuss advantages and disadvantages of the method.

Methods: VC and 3DVR in space analysis were performed using Syngo 2006G platform by Siemens Medical Systems in: a 46-year-old man with a spastic colon and some intestinal diverticula and polyps, a 65-year-old man who underwent endoscopic removal of a large colorectal polyp, a 64-year-old women with large circular cancer stenosis of the rectum and right hepatic lobe metastatic lesion, and a 52-year-old man with a large endoluminal cancer mass in the sigmoid colon. Virtual colonoscopy was performed in real time using ray casting algorithm with space leaping acceleration method. Siemens Somatom Emotion 16 scanner was used for image acquisition. Postprocessing of the images stored in DICOM format was done by dual Xeon workstation.

Results: Fly through algorithm and 3DVR were performed on data sets created from axial CT images collected from multislice helical CT scanner archived in DICOM format. Fly through and 3DVR postprocessing produced a series of images that were analyzed by one radiologist, two surgeons and two physicians experienced in virtual endoscopy.

Conclusion: VC is a useful non-invasive method in the assessment of malignant and benign lesions of colon. It may provide useful additional information for a surgeon during preoperative management. Furthermore, it allows three-dimensional visualization in the lumen beyond areas of narrowing or stenosis and it gives a highly accurate representation of colorectal lesions. Its disadvantages are that it does not provide histology, it requires an air-mucosa interface to produce an image and it cannot identify functional lesions. Using VC, clinicians can appreciate not only the intraluminal proliferation of the tumor but also the extraluminal extension of the mass and its relation to the surrounding organs.

KEY WORDS: *high resolution computed tomography, virtual colonoscopy, 3D volume rendering, colorectal cancer*

VIRTUALNA KOLONOSKOPIJA I 3D REKONSTRUKCIJE U BOLESNIKA S KARCINOMOM KOLONA I REKTUMA

Sažetak

Uvod: Virtualna endoskopija kolona ili virtualna kolonoskopija (VC) je metoda postprocesiranja podataka dobivenih kompjutoriziranom tomografijom visoke razlučivosti. VC simulira pogled pravog endoskopa na unutrašnju površinu debelog crijeva, a izvodi se u realnom vremenu na računalnim radnim stanicama s pomoću računalnog algoritma "ray casting". VC se može izvoditi zajedno sa trodimenzionalnim volumnim renderiranjem (3DVR) koje daje 3D prikaz promatranog dijela tijela. VC se može koristiti u edukaciji, dijagnostici, planiranju endoskopskih zahvata ili operacija, te intraoperacijskoj

navigaciji. Kao neinvazivna tehnika VC je naročito korisna ako bolesnik ne može podnijeti klasičnu fiberoptičku endoskopiju ili je ova kontraindicirana..

Ciljevi rada: Uvođenje VC kao nove metode postprocesiranja podataka dobivenih spiralnom kompjutoriziranom tomografijom visoke razlučivosti u ranu dijagnostiku (screening), prijeoperacijsku dijagnostiku i obradu bolesnika, te prikaz prednosti i nedostataka ove metode.

Metode rada: VC i 3DVR učinjene su s pomoću specijaliziranog programskog paketa Syngo 2006G Platform proizvođača Siemens Medical Systems u: četrdesetšestogodišnjeg muškarca sa spastičnim kolonom te nekoliko intestinalnih divertikula i polipa, šezdesetpetogodišnjeg muškarca koji je podvrgnut endoskopskom uklanjanju velikog kolorektalnog polipa, šezdesetčetverogodišnje žene s opsežnom cirkularnom stenozom rektuma i metastazama u desnom hepatalnom režnju, te pedesetdvogodišnjeg muškarca s velikom endoluminalnim karcinomom u sigmoidnom kolonu. Virtualna kolonoskopija napravljena je u realnom vremenu s pomoću "ray casting" algoritma uz "space leaping" metodu akceleracije. Siemens Somatom Emotion 16 CT uređaj primijenjen je za prikupljanje podataka. Postprocesiranje slikovnih CT prikaza pohranjenih u DICOM formatu napravljeno je na radnoj stanici s dva Xeon procesora.

Rezultati: "Fly through" algoritam i 3DVR primijenjeni su nad skupom slikovnih podataka iz aksijalnih CT prikaza dobivenih višeslojnim CT uređajem i pohranjenim u DICOM formatu. VC i 3DVR postprocesiranje rezultiralo je serijom slikovnih prikaza koje su analizirali jedan radiolog, dva kirurga i dva liječnika s iskustvom u virtualnoj endoskopiji.

Zaključak: VC je korisna neinvazivna tehnika za probir i procjenu benignih i malignih lezija kolona. VC može pružiti korisne dodatne informacije kirurgu prilikom prijeoperacijske obrade bolesnika. Nadalje, virtualna kolonoskopija pruža mogućnost trodimenzionalne vizualizacije lumena crijeva iza područja suženja ili stenoze te pruža vrlo pouzdan prikaz kolorektalnih lezija. Njezin nedostatak je da nije moguće napraviti biopsiju, zahtijeva granicu zrak-sluznica za generiranje slikovnog prikaza te ne može identificirati funkcionalne lezije. Primjenom ovih tehnika kliničari mogu procijeniti ne samo intraluminalnu proliferaciju tumora već i ekstraluminalno širenje tumorske mase te odnos prema okolnim anatomskim strukturama.

KLJUČNE RIJEČI: *kompjutorizirana tomografija visoke razlučivosti, virtualna kolonoskopija, 3D volumno renderiranje, kolorektalni karcinom*

INTRODUCTION

Colorectal cancer represents the second leading cause of cancer death in the United States and also in most other industrialized countries. It accounts for approximately 10% of all cancer deaths in both men and women combined (1, 2). The majority of cases of colon cancer develop in patients without specific risk factors. The current recommendation for colon cancer screening in asymptomatic patients at average risk for colorectal cancer is that it should begin at age of 50 years (1).

In recent years, the incidence and mortality of colorectal cancer have declined. Early diagnosis and preventive removal of premalignant adenomatous polyps are believed to be the most probable reasons for a decrease in both incidence and mortality of colorectal cancer. This is related to the increased use of colonoscopy (3). However, the cumulative lifetime risk for the development of colorectal cancer is still approximately 5% (4).

It is generally accepted that the vast majority of colorectal cancers arise from adenomatous polyps. Bearing in mind that malignant transformation is found in approximately 1% of polyps of less than 10 mm in size, compared with 10% of larger polyps (5), early detection of colorectal polyps might be regarded as one of the major goals in health care management (3).

Several studies have focused on the role and principal characteristics of virtual endoscopy of the colon (virtual colonoscopy) in colorectal cancer prevention and detection (6-12).

Virtual colonoscopy has several advantages over existing colorectal cancer screening techniques. As a full structural colonic examination, its diagnostic potential should be much greater than fecal occult blood testing and, for the same reason, it should yield substantially more neoplasms than flexible sigmoidoscopy. As a total colonic examination it competes directly with barium enema and classical fiberoptic colonoscopy (8).

Complete colonoscopy allows the most thorough evaluation of the colon, with the added benefit of the ability to perform biopsy or excision of suspicious lesions. Colonoscopy is considered the reference standard for colonic evaluation (1, 3, 13).

However, there are several important limitations to the widespread use of screening colonoscopy (3), including the need for sedation, the po-

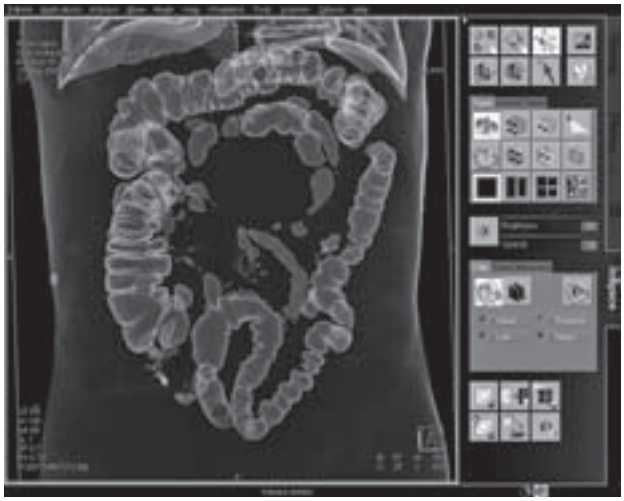

Figure 1. 3DVR double air contrast reconstruction was performed after the air insufflation into the rectum. It may be used to estimate whether the air insufflation was successful. Furthermore, this method gives a general overview of the anatomical relationships of the large and partially of the small bowel. It is useful for clinicians to perform double air 3DVR before actual virtual colonoscopy or CT colonography because it may provide information which may be used by the clinician to make decision where to focus his attention during the virtual colonoscopy procedure. Sometimes cancer of a medium or large size may be revealed with this procedure. Relatively well colonic distention and cleansing in the 46-year-old man was shown.

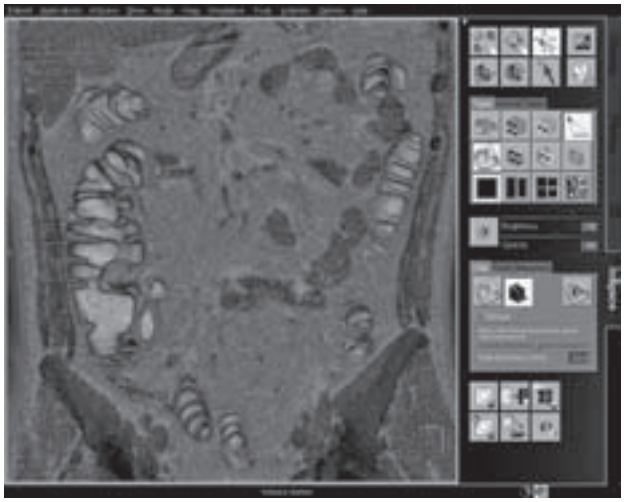

Figure 2. 3DVR reconstruction of the same region using an algorithm for segmentation of colonic epithelial surface. The frontal clipping plane was used to remove some tissue in order to provide a clear fly-over view to the ascendant colon.

tential risk of perforation and bleeding (0.1%–0.3% of cases), the costs of the procedure (including the need for sedation), a failure to complete the ex-

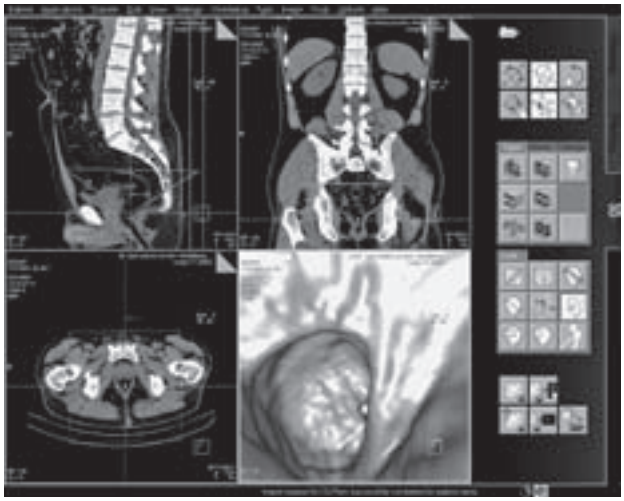

Figure 3. High resolution computed tomography accompanied with VC and 3DVR was performed in the 46-year-old man suffering from colonic cramps. Virtual endocamera was situated within the rectum lumen and its view focused upwards. VC working environment was divided in four windows. Virtual endocamera endoluminal position was shown in three main coordinate planes. Reconstructed endocamera view was presented in the fourth window. Endocamera view was focused in cranial direction within the sigmoid colon. Normal endoluminal appearance as presented by the fly-through procedure was shown.

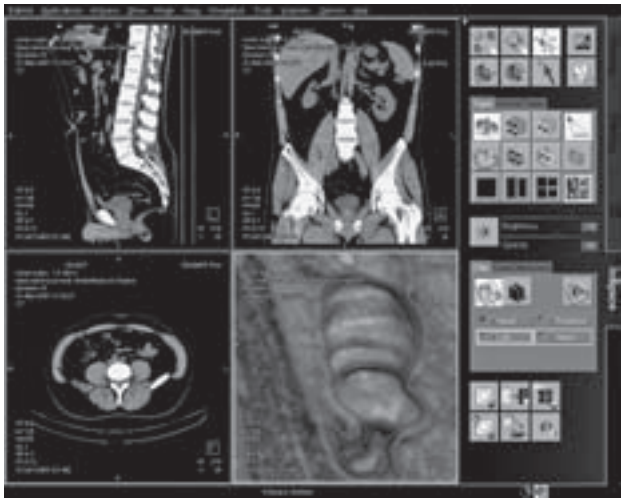

Figure 4. 3DVR in space fly-over environment. HRCT reconstructions in three main coordinate planes were presented in the first three windows. In the fourth window, fly-over 3DVR reconstruction was performed. Part of the descendant colon was opened and functional circular stenosis due to colonic spasm was revealed. Colonic mucosa, its wall and surrounding tissue appearance around the colon was normal and without a sign of tumor.

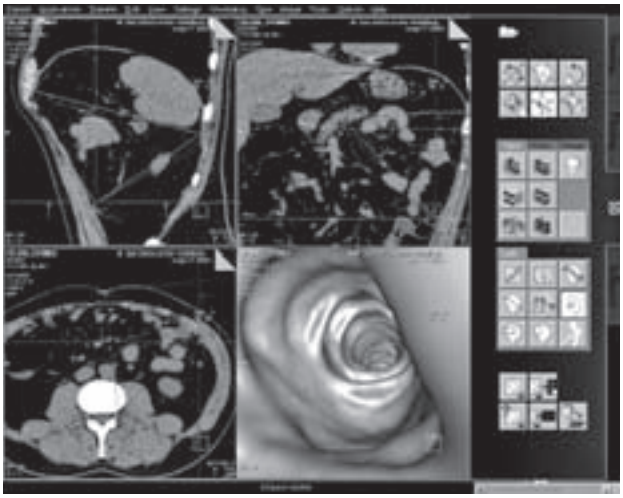

Figure 5. Virtual endocamera was positioned within the descendant colon and its view oriented upwards. Normal circular colonic haustra were presented by fly-through reconstruction.

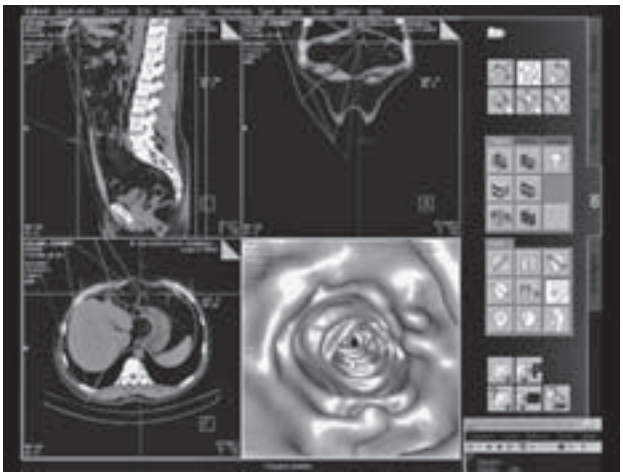

Figure 6. Fly-through within the transversal colon was shown. Virtual endocamera was located approximately in the mediosagittal plane and its view oriented towards the right side of the body. A small amount of residual fecal mass and contrast medium was presented. For an inexperienced user, it is important to say that these residuals may be mistaken for small intestinal polyps therefore it is important not only to look at 3D reconstruction but also reference CT reconstructions in all the three coordinate planes. The relationship of this endoluminal intersection and position of virtual endocamera to surrounding abdominal anatomical structures may also be studied on these three planes.

amination in 5%–10% of patients, and an insufficient workforce of trained endoscopists to meet the increased demand (14, 15). For these reasons, virtual colonoscopy (CT colonography) is being investigated and used clinically to evaluate the colon for polyps and cancers (3, 6).

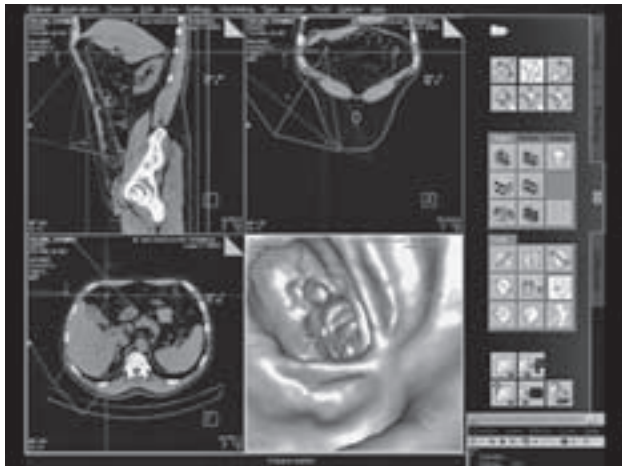

Figure 7. A small intestinal polyp within the border intestinal segment between the transversal and ascendant colon was presented. The polyp was located on the anterosuperior bowel wall.

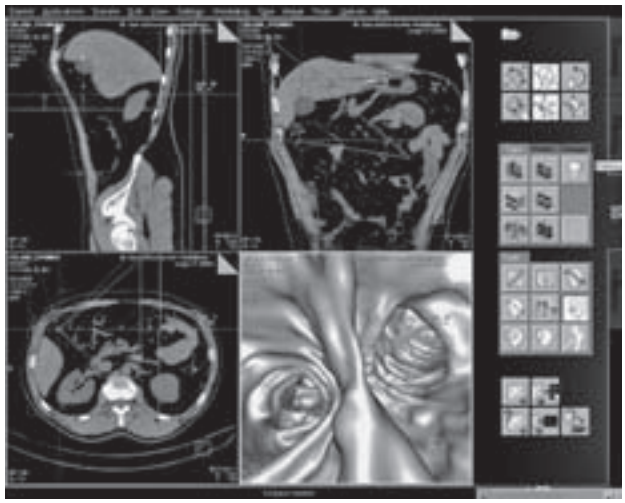

Figure 8. Virtual endocamera was located on the border part between the transversal and ascendant colon. Its view was directed towards the colonic wall on the inflexion point therefore both lumens of the transversal colon and the ascendant colon were shown.

Clinical evaluation of virtual colonoscopy has shown promise for the detection of polyps and cancers of the colon and rectum, with per-polyp sensitivity values ranging from 75% to 100% for polyps 10 mm and larger (8). For thin-section multi–detector row CT, the per-patient specificity for lesions 10 mm and larger is greater than 95% (16, 17).

Several studies showed virtual colonoscopy to be as effective as conventional colonoscopy for

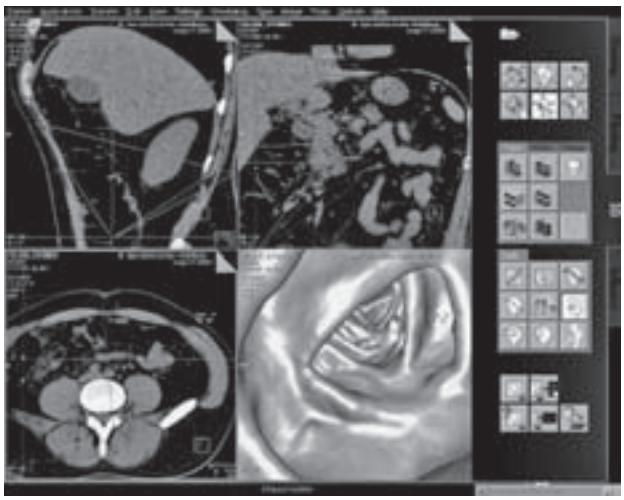

Figure 9. Virtual endocamera was located within the ascendant colon. Normal anatomical structure was shown without visible pathology.

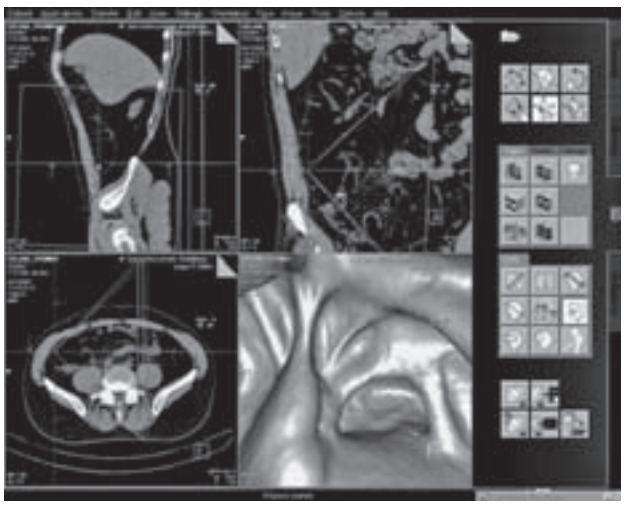

Figure 10. Virtual endocamera was situated within the cecum and its view directed towards the Bauchini valve. Normal endoluminal appearance was shown.

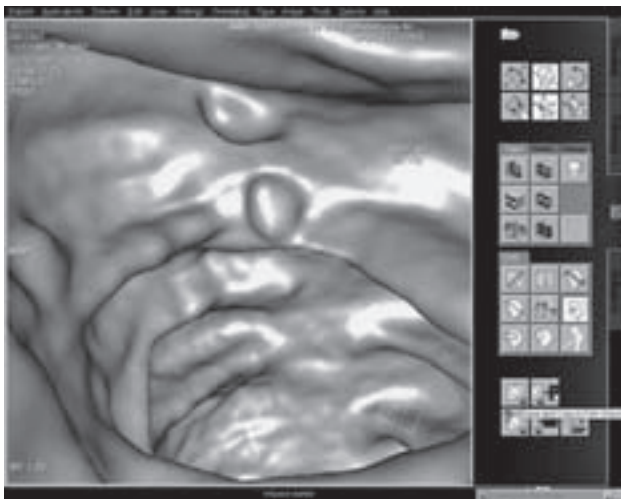

Figure 11. Virtual endocamera revealed two small intestinal polyps less than 10 mm in diameter.

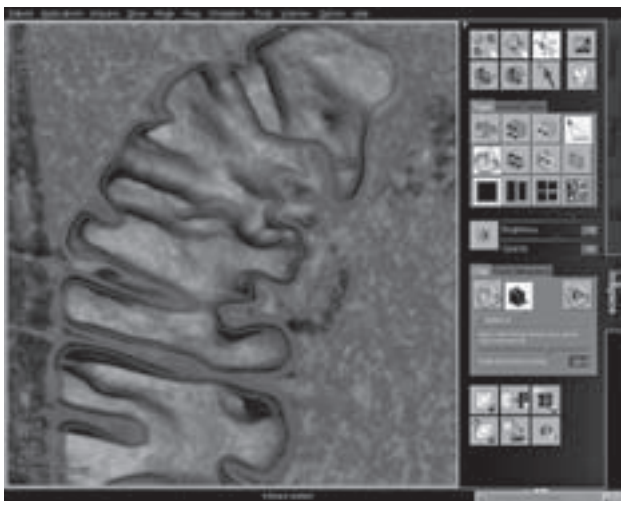

Figure 12. 3DVR reconstruction of the ascendant colon. Ostium of the small colonic diverticle was presented.

the detection of polyps 10 mm and larger (16, 18). However, fundamental differences between the two methods remain: biopsy specimens cannot be obtained by virtual colonoscopy, and surrounding tissues and anatomic structures in relation to endoscope position cannot be visualized during classical flexible endoscopy. Furthermore, due to the sedation medication, classical fiberoptic colonoscopy procedures usually require 30 minutes to 2 hours recovery time, while VC procedures require no recovery time.

Although VC is a non-invasive procedure, a colon preparation similar to that required for fiberoptic colonoscopy including Dulcolax, phosphosoda and oral contrast agents is used. During a VC procedure patients are exposed to a small amount of radiation. Since the procedure is non-invasive, there is no risk of colon perforation. There is no exposure to radiation during a fiberoptic colonoscopy procedure, but approximately 3 in 1,000-10,000 patients experience complications due to perforation.

3DVR has made significant contributions in surgical planning. A majority of surgical proce-

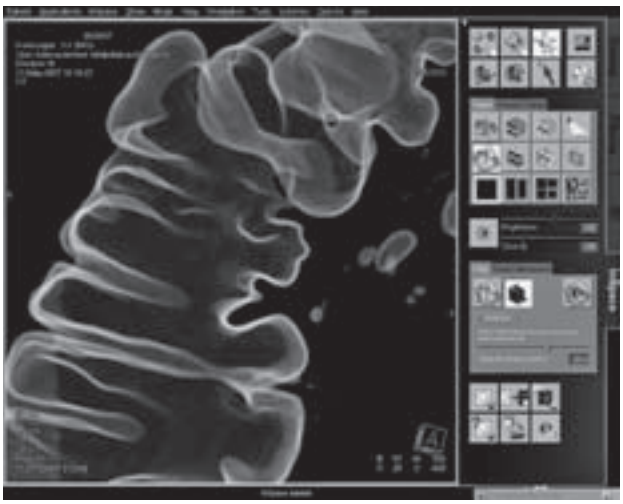

Figure 13. 3DVR double air contrast reconstruction of the same anatomic region presented on the previous picture.

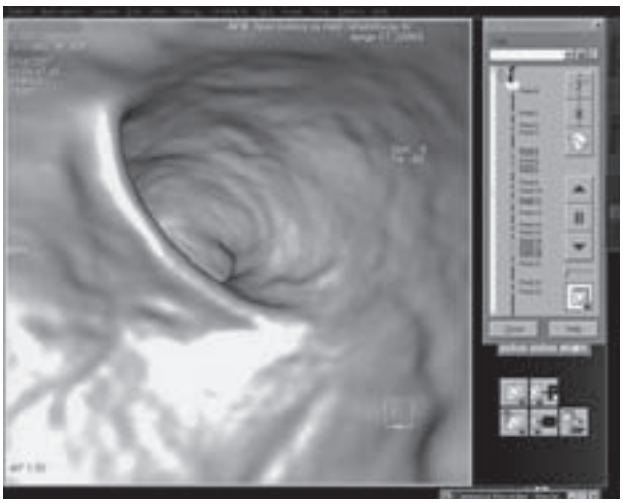

Figure 15. Fly-through within the rectum of a 65-years-old man with a positive test for occult bleeding. Due to the bleeding, classical colonoscopy was performed and one polyp on the rectal wall was found and removed.

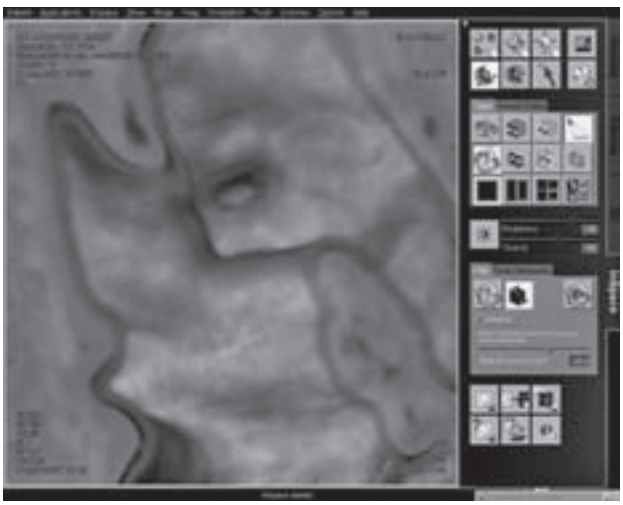

Figure 14. 3DVR enlarged view clearly revealed the diverticulum's position.

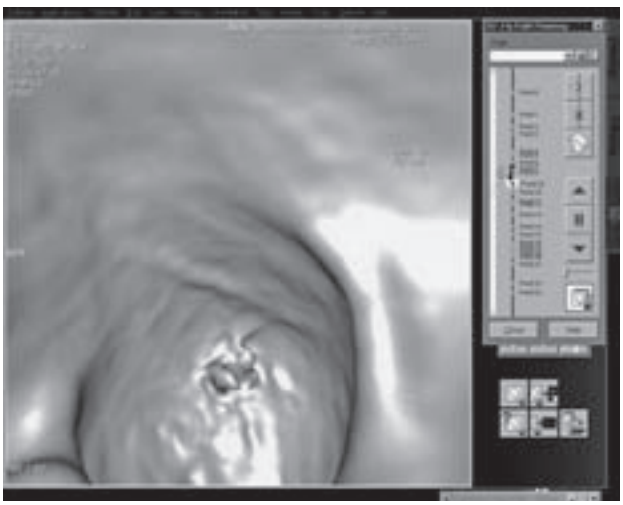

Figure 16. Endocamera view was directed towards the site where the removed polyp has been found. Residual scar on the wall was presented.

dures involve a complex 3D relationship between the affected tissue and adjacent anatomic structures (19).

The objective of this paper was to find out advantages and disadvantages of VC and 3DVR in the screening and management of colorectal cancer as well as to implement these methods in practice.

METHODS

MSCT of the abdomen accompanied by VC and 3DVR postprocessing was performed in: a 46-year-old man with a spastic colon and some intestinal diverticula and polyps, a 65-year-old man who underwent endoscopic removal of large colorectal polyp, a 64-year-old women with large circular cancer stenosis of the rectum and right hepatic lobe metastatic lesion, and a 52-year-old man with a large endoluminal cancer mass in the sigmoid colon.

Before MSCT scanning, all patients underwent full bowel cleansing and air distension of the colon using a rectal enema tube. A small rubber

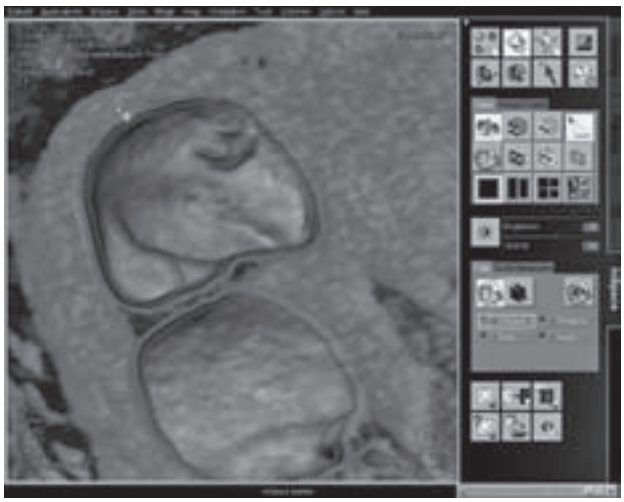

Figure 17. 3DVR reconstruction of the same anatomical region in the patient from previous picture. Larger part of the rectum and its anatomical relationship to surrounding tissue were presented. The mentioned postoperative scar was displayed more plastically and with ability to evaluate its position in relation to surroundings.

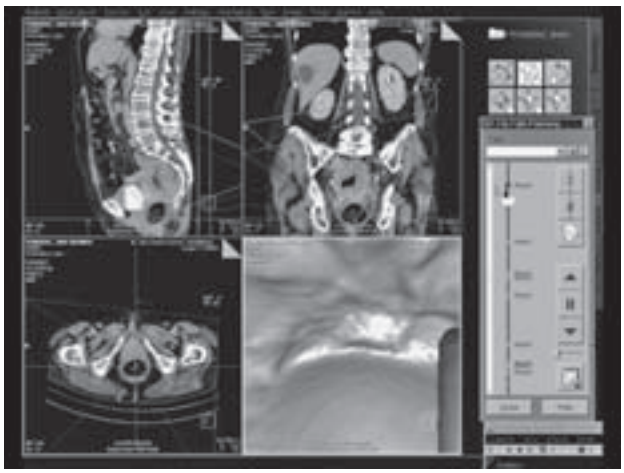

Figure 18. Virtual endoscopy of the rectum in the 64-year-old women with large circular cancer stenosis of the rectum. Presacral space, uterus and adnexa were infiltrated by cancer. A large metastatic lesion in the right hepatic lobe was visible within the frontal reconstruction plane. Few enlarged retroperitoneal lymph nodes were found in the sagittal reconstruction plane. Fly-through revealed circular stenosis.

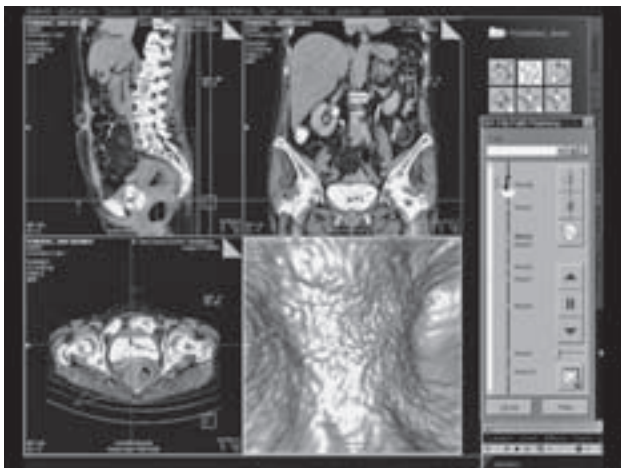

Figure 19. In order to evaluate possible cancer spread towards the posterior urinary bladder wall we performed virtual cystoscopy. Virtual endocamera was situated within the bladder and directed towards the posterior wall. Normal appearance was found without signs of cancer infiltration.

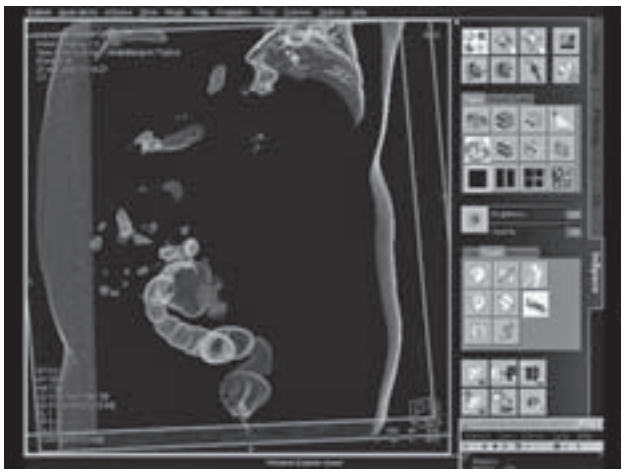

Figure 20. 3DVR double air contrast reconstruction was performed in the 52-year-old man after the air insufflation into the rectum. This method clearly revealed bowel obstruction with large endoluminal cancer located within the sigmoid colon therefore only part of the bowel was distended with air. Air is visible only in the rectosigmoid colon towards the cancer location whereas the bowel proximally to the cancer was not visible due to impossibility of air passage.

catheter can be used to insufflate the colon. Acquisition of both supine and prone thin-section images of the colon was done by a Siemens Somatom Emotion 16 scanner (slice thickness 1.2 and 0.6 mm). Acquired images were stored in the DICOM format. Data interpretation was performed by a multidisciplinary team analyzing a combination of axial and multiplanar or endoluminal VC as well as 3DVR reconstructions. Postprocessing was done on a dual Xeon workstation using the professional 3D Syngo CT 2006G software package. Additional views and reconstructions not normally accessible by conventional endoscopy were generated.

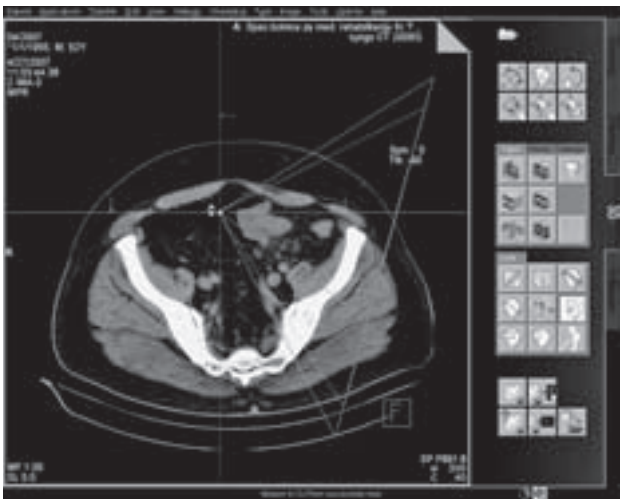

Figure 21. HRCT scan of abdomen in the axial plane revealed the above mentioned cancer of the sigmoid colon. Virtual endocamera view directed towards the tumor.

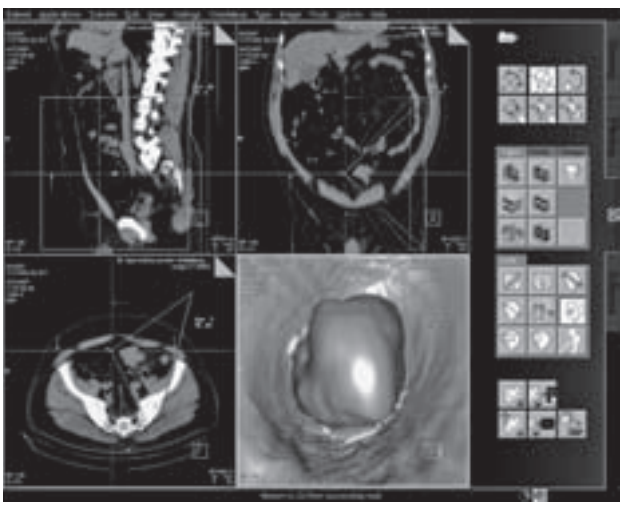

Figure 22. Fly-through within the sigmoid colon of the same patient. A large endoluminal cancer mass was presented.

RESULTS

Fly-through of the virtual endocamera within the bowel lumen was both manually and automatically driven. We interactively changed the camera 3D position and focus during examination using a mouse pointing device.

VE and 3DVR processing were performed by a multidisciplinary team – one radiologist, one general surgeon and two physicians experienced in VC.

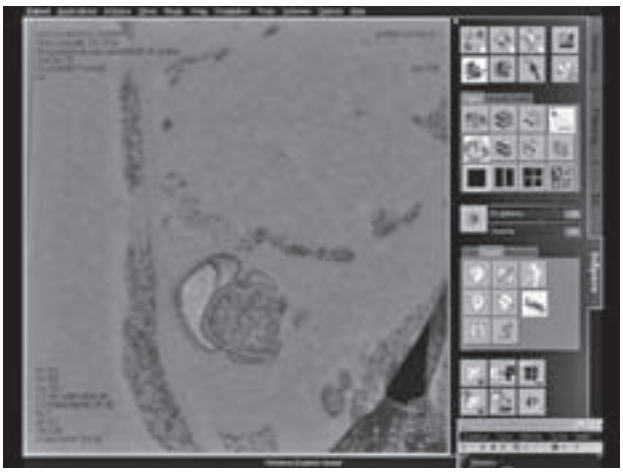

Figure 23. 3DVR reconstruction in the same patient revealed the tumor relationship to the bowel wall and surrounding structures.

DISCUSSION

Visualization of volumetric medical image data plays a crucial part for diagnosis and therapy planning. In recent years, computerized post-processing techniques of image data from cross-sectional imaging modalities have received increasing recognition in the field of medicine. Technical developments of acquisition systems such as multislice CT and MRI have improved along with continuously increasing spatial resolution. Various post-processing techniques have been available, to enable the radiologist or surgeon to recognize a pathological condition in the shortest amount of time: three 2D orthogonal views, maximum intensity projection (MIP), surface and 3D volume rendering.

The advancement of high resolution computed tomography with thin sections and intravenous contrast has greatly improved the clinician's ability to diagnose various lesions, allowing for earlier detection and more accurate staging.

Virtual colonoscopy is a novel and rapidly evolving technique for colonic examination, and it is especially useful for colorectal cancer screening. Many factors influence successful performance of VC. An understanding of these factors and continued efforts to improve them will help ensure widespread implementation of VC into routine clinical practice. (20) Virtual colonoscopy may improve colorectal screening by facilitating detection of clinically important colorectal polyps with the use of a relatively noninvasive safe examination,

thereby increasing patient and clinician acceptance of colon cancer screening (8, 21).

Some studies reported that with interrogation of 3D endoluminal images in both anterograde and retrograde directions, smaller polyps (up to 5 mm) can be routinely detected by virtual colonoscopy (16).

The polyp size is clinically a single, the most important feature of a colorectal polyp because it serves as a rough gauge for the risk of carcinoma and so it dictates patient care. Therefore, polyps should be measured accurately and reliably at VC and patient management should be done according to the reported polyp size. Polyps measuring 10 mm should be reported with a recommendation for therapeutic colonoscopy (22, 23).

Reporting of polyps measuring 5 mm is not recommended because they often represent false-positives and they are frequently non-neoplastic or are associated with an extremely low risk of malignancy (22, 23). The potential harm of fiberoptic colonoscopy may outweigh the benefits for patients with diminutive polyps. Reporting of polyps measuring between 6-9 mm varies, depending on the specific lesion size, the certainty of the findings, patient's age and existing comorbid conditions (22). One guideline that used the CT Colonography Reporting and Data System (C-RADS) classification scheme suggested immediate colonoscopy for patients with three or more 6-9 mm polyps and follow-up colonoscopy should be done in three years for patients with less than three 6-9 mm polyps (23).

The current reimbursable classical methods available for colorectal carcinoma screening include fecal occult blood testing, sigmoidoscopy, double contrast barium enema examination, colonoscopy, and combinations of these tests.

Screening sigmoidoscopy has been shown to decrease the mortality due to colorectal cancer. However, sigmoidoscopy is not an evaluation of the entire colon, and, therefore, complete colon screening is not achieved.

Classical fiberoptic colonoscopy is considered the reference standard for colonic evaluation (1, 13), but it has several important limitations to be used for screening including the need for sedation, the potential risk of perforation and bleeding, the costs of the procedure and sedation, a failure to complete the examination in 5%–10% of patients, and an insufficient workforce of trained endoscopists to meet the increased demand (14, 15). For these reasons, virtual colonoscopy (CT colonography) is being investigated and used clinically to evaluate the colon for polyps and cancers.

There are many factors affecting the successful performance of VC. Adequate colonic cleansing and distension, the optimal CT technique and interpretation with using the newest VC software by a trained reader will help ensure high accuracy for lesion detection. Fecal and fluid tagging may improve the diagnostic accuracy and allow for reduced bowel preparation. Automated carbon dioxide insufflation is more efficient and may be safer for colonic distension as compared to manual room air insufflation. CT scanning should use thin collimation of 3 mm with a reconstruction interval of 1.5 mm and a low radiation dose. There is not any correct method for the interpretation of VC, therefore, readers should be well-versed with both the primary 3D and 2D reviews. Polyps detected at VC should be measured accurately and reported following the polyp size-based patient management system (20).

On one hand, IV contrast enhancement is helpful for differentiating polyps from fecal residues (24, 25) and for improving the detection of polyps in suboptimally prepared colons (26). Yet, it is not routinely used with screening CTC due to its risk and uncertain cost-effectiveness (22). On the other hand, IV contrast enhancement is important for the detection and characterization of clinically significant extracolonic abnormalities. Therefore, it is necessary to use contrast enhancement for patients with known colorectal cancer or if they have the suspicion of it, for patients who are followed up after curative surgery for colorectal cancer and for those patients with symptoms that suggest an increased prevalence of extracolonic abnormalities (22, 27).

CONCLUSIONS

Virtual colonoscopy is a useful non-invasive method for screening and the assessment of malignant and benign lesions of the colon. It is especially useful for colorectal cancer screening. Many factors influence the successful performance of VC. An understanding of these factors and contin-

ued efforts to improve them will help ensure widespread implementation of VC into routine clinical practice. VC may provide useful additional information for a surgeon during preoperative management. Its disadvantages are that it does not provide histology, it requires an air-mucosa interface to produce an image and it cannot identify functional lesions.

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