Technical Report

Virtual Pyeloscopy Using Volumetric Depth Peeling[1]

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Rationale and Objectives. The aim of the study is to test a new volume-rendering method, volumetric depth peeling (VDP), for use in virtual pyeloscopy.

Materials and Methods. VDP was applied to axial contrast-enhanced source computed tomographic (CT) images and coronal reformatted maximum intensity projections of three contrast-filled gloves containing objects of varying density. Similar renderings were performed on CT urograms performed to evaluate hematuria (n = 20). Renderings were assessed for anatomic appearance of ureters and specific calyces in comparison with source images.

Results. Objects of soft-tissue and calcific density ranging in size from 4 to 20 mm were identified by using VDP within the glove phantoms. Normal and deformed renal calyces were well visualized by using VDP; however, two stones were not identified. The minimal ureteral width that could be visualized was 3 mm.

Conclusion. VDP may be a useful technique for virtual pyeloscopy providing that a robust and user-friendly computer interface can be developed.

Key Words. Volume rendering; kidneys.

Intravenous urography, ultrasound, and computed tomography (CT) have been used widely during the past decades in evaluating the urinary tract, especially painless hematuria. The advent of multidetector CT enables the acquisition of thinly collimated slices that improve spatial resolution. Three-dimensional imaging reconstruction techniques, including maximum intensity projection (MIP) and volume rendering, use these high-resolution images to form representations of the collecting system that can be viewed in the coronal plane, usually referred to as CT urography (CTU). This technique, despite its relatively high radiation dose, has replaced intravenous urography as the test of choice for evaluation of painless hematuria. Several groups reported excellent results in the identification of urothelial-based lesions by using the technique (1–4). CT cystography with air insufflation of the bladder can show lesions as small as 2 mm on axial images alone (5,6).

Review of axial source and coronal or sagittal reformatted images enables the operator to visualize anatomic relationships clearly in and around the kidney. Tumors of the urothelial system can be identified and staged with a single test. The missing piece is the ability to change the viewing angle of the operator. Virtual endoscopy is a perspective imaging technique designed to create such simulated endoscopic views. There is a broad range of potential applications for virtual endoscopy, such as diagnosis, preoperative planning, and simulation of a surgical procedure for training purposes.

Volumetric depth peeling (VDP) is a variant of volume rendering that enables display of otherwise occluding features in volume sets (7). The technique

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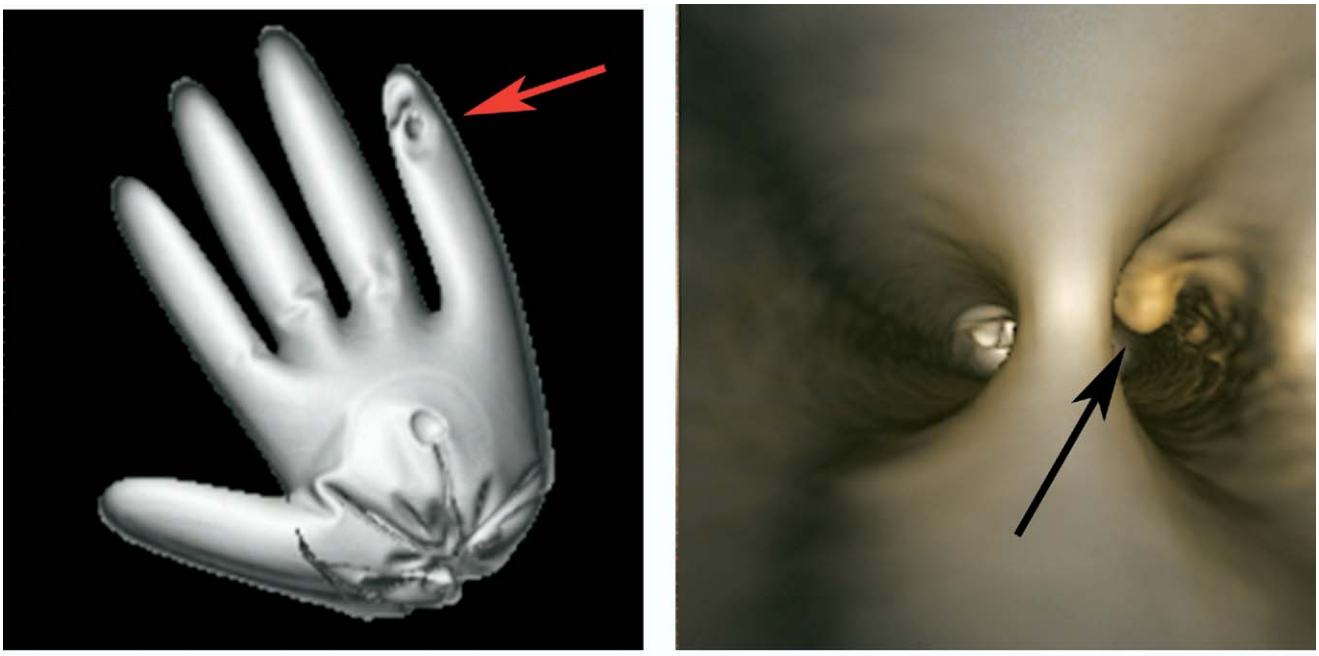


a. b.

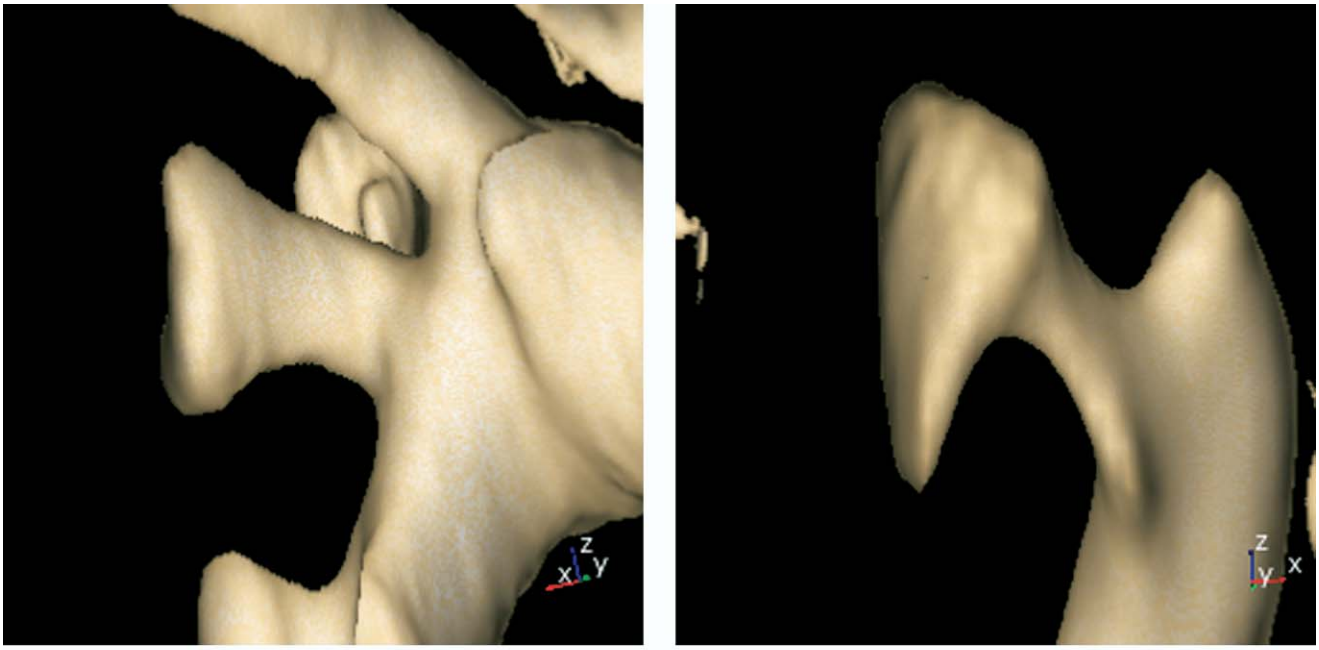
Figure 1. **(a)** Long- and **(b)** short-axis views of a VDP volume rendering of a glove phantom show a small soft tissue density object arising from the independent side of the fifth digit (arrow).

works by separating occlusion determination from the volume-rendering transfer function. In the case of contrast-enhanced CT, the contrast is used to determine occlusion. Material between the viewer and the far side of the contrast is peeled away, enabling views of the internal aspect of the structure from exterior viewpoints.

VDP is uniquely suited to viewing the internal architecture of the renal calyces and ureters. Because the camera angle is infinitely variable, a specific calyx can be visualized along its long or short axis in addition to the standard coronal and axial planes. Standard CT urograms and axial source images are displayed simultaneously to improve the operator's confidence in the location of the exact location of the abnormality with respect to a standard endoscope. Spatial resolution is that of the source images, usually 512 × 512 pixels in the axial plane and .75–1.5 mm in the sagittal/coronal planes. Therefore, the thinner the collimation in the axial plane, the better the spatial resolution of the volume-rendered calyx. No presegmentation is required; therefore, this is a rapidly performed technique. To determine whether VDP is a viable technique for pyeloscopy, we designed a prospective pilot study in vitro and in vivo.

MATERIALS AND METHODS

All images were obtained by using a Siemens 16 slice multidetector CT scanner (Erlangen, Germany). In vitro, a latex glove filled with dilute water-soluble contrast material with density similar to that of the renal collecting system in the excretory phase of a CT urogram (1100 HU) and placed in an agar bath was scanned by using a CTU protocol. Objects of air, water, and calcific density ranging from 4 to 20 mm were glued to the interior surface of the glove's digits. The superior side of the glove was labeled independent, and the inferior side, dependent. Axial source and coronal MIP images were produced. For the in vivo portion of the study, images from 10 consecutive patients (n = 20 kidneys) who underwent CTU as part of routine clinical care for the diagnosis of painless hematuria were compiled. Standard CT protocol was 120 kv, 1.5-mm slice collimation, and variable milliamperes, depending on patient thickness. Only the excretory-phase axial source images and coronal MIP images were stored. Use of this anonymized patient data was approved by our institution's review board. All images then were transferred to CD-ROM and processed by using the VDP algorithm on a Dell Inspiron 5160 laptop (Dell, Inc., Round Rock, Texas, USA) with a 2.8 GHZ Pentium 4 pro-



a. b.

Figure 2. Oblique coronal approach using VDP volume rendering shows a **(a)** normal calyx and **(b)** deformed bulbous calyx.

cessor and 1 GB of RAM. The algorithm is software based; thus, the impact of the graphics card used is negligible. The operator making the VDP renderings was masked to the presence or absence of objects within the glove phantom. Because identification of particular calyces was difficult without training in radiology, review of the in vivo VDP renderings was done in consensus with a radiologist.

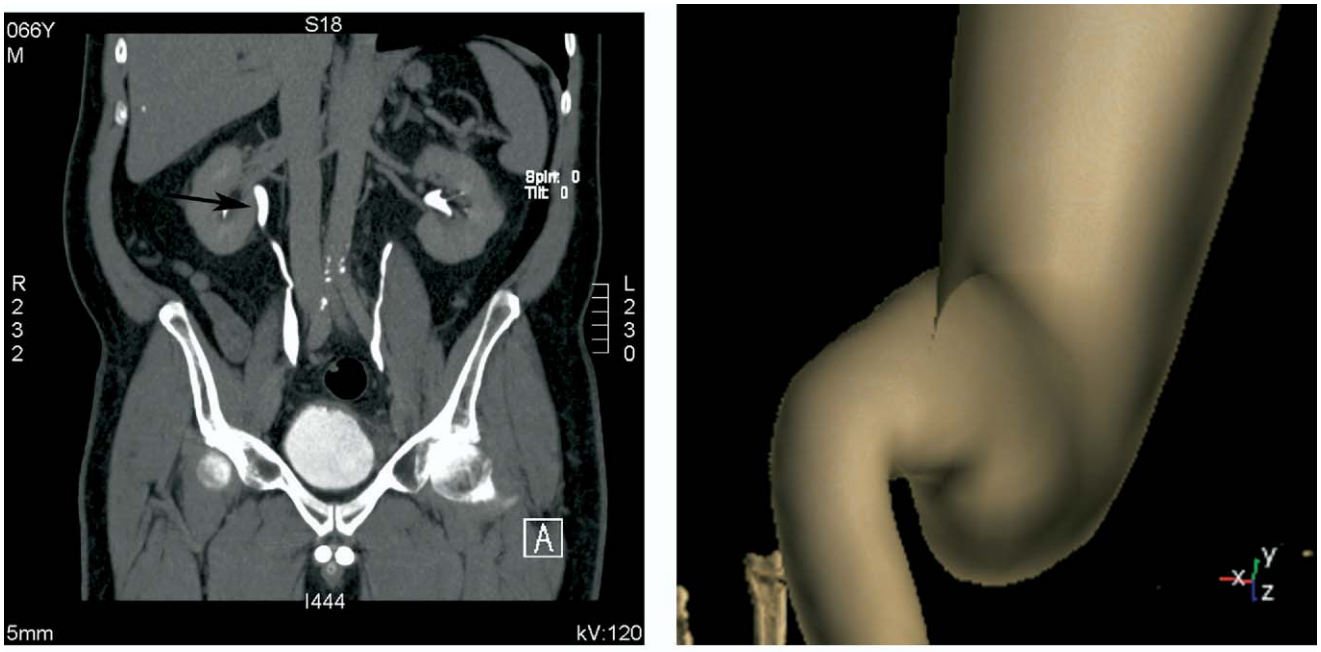
RESULTS

For the in vitro portion of the experiment, glove 1 contained no objects, glove 2 contained a calcium density shell measuring 20 × 10 × 8 mm on the dependent side of digit D (with thumb defined as A) and a stone measuring 4 × 7 × 4 mm on the dependent side of digit B. Glove 3 contained a mixed air and soft tissue density object measuring 10 × 6 × 5 mm on the independent side of digit A and a soft tissue density object measuring 9 × 4 × 7 mm on the independent side of digit E (Figure 1). All objects were identified, and there were no false-positive results. Of note, the unlimited camera angle allowed the operator to view the glove in its entirety both internally and externally, allowing for rapid identification of objects.

For the in vivo portion of the experiment, the radiologist chose specific calyces, one within each kidney, for review based on abnormal anatomy or presence of stone. No urothelial tumors were identified on source images or cystoscopy. VDP was applied successfully to CT images of 19 kidneys. Multiple metal clips within one kidney distorted the endoscopic view, making it impossible to clearly identify the walls of the calyces. In addition, fly-throughs of all ureters were performed. Fifteen normal calyces, three deformed calyces, and one site of extrinsic compression caused by a crossing vessel were clearly shown (Figure 2). Two stones, one 3 mm and the other 9 mm, were not identified. All contrast-filled portions of the ureter could be virtually traversed; the minimal ureteral diameter measured on source images was 3 mm (Figure 3).

DISCUSSION

In this pilot study, VDP was successful in identification of calyceal distortion and masses 4 mm in width. Infundibula with a minimum diameter of 2 mm and ureters with a minimum diameter of 3 mm could be navigated with confidence. It is unlikely that diameters less than these can be navigated because of the spatial resolution of the source images. However, in general, this would be unlikely to limit clinical usefulness. Stones were not identified, likely because the density was similar to that of adjacent contrast material



a. b.

Figure 3. **(a)** Coronal MIP image (arrow) and **(b)** VDP volume rendering of a tortuous ureter measuring approximately 5 mm in diameter. In this case, the ureter is viewed caudally and from outside the wall for ease of comparison.

and removed during computer processing. It is possible that the algorithm may be modified to identify at least very high-density stones (>2000 HU). Fortunately, most CT examinations of the kidneys begin with a non–contrast-enhanced scan that clearly shows stones of virtually any density. At present, metal clips, again of high density, preclude use of the technique.

There has been relatively little experimentation with virtual pyeloscopy, likely because limited spatial resolution and the complexity of the internal architecture of the renal pelvis proved formidable barriers to success. Recently, Liatsikos et al (8) reported clear identification of ureteropelvic junction obstruction in five patients by using a single-detector scanner, 3-mm collimation, and standard volume rendering. The renal pelvis and origins of the calyces also were well visualized in 10 volunteers without urological disease. Data processing for the volume rendering required 10–15 minutes. Volumetric depth peeling requires virtually no processing time after importation of axial and coronal data into the computer system.

The ultimate goal of virtual pyeloscopy is to replace surveillance endoscopy in the population with high tumor risk and screening endoscopy in the low-risk population with hematuria. In this small pilot study, only anatomic abnormalities were studied because upper-tract tumors are relatively uncommon and none was identified during our acquisition time frame. Comparison with endoscopic images was not performed because at our institution, retrograde pyeloscopy is not performed unless a tumor must be biopsied. To determine the effectiveness of VDP in identifying tumors, a large prospective study, likely consisting of hundreds of patients with surgical correlation, will be required. Identification of small smooth tumors may be particularly challenging because the smoothing of the data set inherent in volume-rendering techniques may limit edge identification. For obese patients, increased radiation doses may be required to obtain adequate signal to noise. This may entail a fixed milliampere or slowing of the gantry rotation speed. Spatial resolution, once a major problem in any type of virtual renderings, is becoming less of an issue because of the very fine collimation available with the newer generation 64-channel multidetector CT scanners. All volume-rendering techniques, including VDP, are dependent on complete opacification of the urinary tract. Careful attention to optimize acquisition of excretory phase images will be required to use VDP successfully.

At present, the use of VDP requires transfer of Digital Imaging and Communications in Medicine data to a separate computer. Ideally, this algorithm would be integrated into the reading room workstations so that immediate assessment

could be performed of any regions deemed suspicious on the source or reformatted CT images. To be effective, VDP would have to be easily and quickly performed by the operator, usually a radiologist. This likely will require several iterations of the algorithm and thoughtful integration into the workstation.

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