Grey-Scale Ultrasound in the Imaging of Urinary Tract Disease

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Grey-scale ultrasound defines smaller renal lesions that had previously been appreciated and is able to define associated lesions of the liver such as metastases and cysts. The appropriate technique to delineate the normal anatomy of the kidney is described. Ultrasound plays a central role in the identification and characterization of renal mass lesions thus leading to appropriate further work up. In renal transplant evaluation ultrasound is useful as a complementary modality to other imaging studies permitting the recognition of pelvic fluid collections, rejection, and hydronephrosis. Specific findings are present in renal abscess, perirenal abscess, and in several of the renal cystic diseases. Adrenal lesions can be identified and clarified. In the lower urinary tract, ultrasound can identify bladder and prostatic tumors.

Ultrasound provides a rapid, safe and non-invasive modality which is complementary to other imaging techniques in the diagnosis of urinary tract disease.

INTRODUCTION

Ultrasound has become a standard imaging modality in the diagnosis of renal and perirenal disease. Grey-scale ultrasound defines smaller renal lesions than had previously been appreciated and defines associated lesions of the liver such as metastases and cysts [1]. Compared with the previous bistable equipment, grey-scale ultrasound offers better signal to noise ratio and improved resolution. The purpose of this communication is to define the role of grey-scale ultrasound as a complementary imaging technique to other modalities and to illustrate some uses of ultrasound in diagnosing urinary tract disease which have been described since the preparation of our recent review of the subject [2].

Patients suspected of urinary tract disease were examined using standard Picker EDC or Searle PhoSonic equipment. The initial examination was performed with the patient supine using the liver as an acoustic “window” to the right kidney. The transducer was placed under the costal margin and then moved in a simple arc through the liver and right kidney. The resulting scan demonstrates a characteristic homogeneous echo pattern within the liver and lower level echoes with the parenchyma of the kidney (Fig. 1A). The cortex appears more echogenic than the medulla. Transverse scans were obtained with the patient supine (Fig. 1B). Subsequent examinations of both kidneys were obtained in transverse axes with the patient either prone or supine and the transducer on the lateral aspect of the patient [3]. For additional delineation of the kidney, the decubitus and upright projections were also obtained, since occasionally a lesion may only be appreciated on a single projection such as the decubitus as shown in Fig. 2. This scanning technique described by Taylor

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FIG. 1A. Longitudinal parasagittal section through the liver (L) and right kidney. The liver is seen to produce a relatively homogeneous echo pattern. The right kidney is posterior to the liver (arrowheads). The central portion of the kidney produces high level echoes representing the collecting system. There is slight separation of these echoes centrally. The cortex produces higher level echoes than the medulla although these echoes are lower level than that of the collecting system.

FIG. 1B. Transverse section through the right kidney with the patient supine. The liver (L) is seen anterior to the right kidney (arrowheads). The collecting system of the right kidney produces high level echoes and is medially located. The cortex is once again noted to be echogenic but with lower level echoes than the collecting system. The columns of Bertin are seen to separate the relatively echo free medullary regions.
and Hill [3], consists of a single pass in a simple arc or line, and produces optimal resolution and minimizes the effects of biological motion since each area is interrogated only once during the scan.

The use of the appropriate frequency for a given patient is important in obtaining an optimal scan. The higher the frequency of the transducer, the better is the resolution. In children, it is particularly important to use a high-frequency transducer. However, since lower frequencies give better penetration, in large adults one frequently must use a lower-frequency transducer to obtain adequate depth. It may be necessary to use a different transducer on the same patient when obtaining scans in a different position.

It is also important to obtain scans, whenever possible, in suspended respiration so that motion does not degrade the resolution. In addition, a high enough gain must be used so that echoes are obtained from the renal and hepatic parenchyma. The technical factors necessary for optimal scanning are summarized in Table 1.

Renal Anatomy

The normal kidney appears on longitudinal section as an elliptical structure the exact contour of which varies with the position in which the scan is obtained and the presence or absence of pathology. The pelvicalceal system is seen as a central collection of echoes (Fig. 1). Echoes are seen from the renal parenchyma which are lower in intensity and less numerous than those in the hepatic parenchyma. Both renal arteries can be identified (Fig. 3) although frequently they are not both seen on the same scan. The right renal vein can be seen as an echo-free structure running from the inferior vena cava to the right kidney (Fig. 4). The left renal vein is the only major vascular structure to run between the superior mesenteric artery and aorta on transverse section. It is recognized in the majority of patients that are scanned (Fig. 5).
FIG. 3A. Transverse section through the abdomen with the patient supine. The right renal artery (arrow) is seen extending from the aorta (A) to the right kidney (K). The superior mesenteric artery (arrowhead) is seen just anterior to the aorta. There are zones of low level echoes in the liver (m) representing metastases.

Obstructive Uropathy

Mild degrees of obstruction to the urinary tract can be recognized as a separation of the central renal echoes. Greater degrees of obstruction may be recognized by a

FIG. 3B. Transverse section of the left upper quadrant with the patient prone. The left renal artery (arrow) is seen extending from the aorta (A) to the left kidney (K). An incidental left renal cyst (c) is seen extending anteriorly to the left kidney.
FIG. 4. Transverse section through the liver (L). The right kidney (k) is seen posterior to the liver. The right renal vein (v) is seen entering the hilum of the right kidney.

| TABLE I | Ultrasound Technique |
|---------|---------------------|
| 1. Single pass | |
| 2. High gain | |
| 3. Appropriate transducer | |
| 4. Suspended respiration | |

single echo-free zone separating the walls of the pelvis (Fig. 6) or by multiple echo-free zones representing dilated calyces [4]. When a non-functioning kidney is found on excretory urography, ultrasound is an important modality in identifying the etiology. Small end-stage kidneys typically have a normal ultrasonographic appearance aside from the small size. The typical patterns observed in the adult polycystic kidney disease and multicystic dysplastic kidney are described below. A renal tumor appears as an echo-containing mass. Although no specific diagnostic criteria have been identified in renal vein thrombosis, the increased size of the kidney which occurs in acute renal vein thrombosis can be appreciated. Thus ultrasound can aid in the clinical decision whether surgical intervention is indicated.

Gross hydronephrosis may be confused with a large cystic mass on ultrasonography. In this situation, the identification of a dilated ureter (Fig. 7) is the most reliable way to make this distinction when the hydronephrosis is due to obstruction to the ureter [2]. When the obstruction is at the ureteropelvic junction or is intrarenal in nature, the differentiation between hydronephrosis and cystic disease may be more difficult. As an example, this four-year-old girl presented with an excretory urogram which showed mild dilatation of the right collecting system and ureter (Fig. 7A). No left kidney was identified. Ultrasound of the right kidney demonstrated a mild right hydronephrosis verifying the findings on urography. Ultrasound examination of the left renal fossa demonstrated an echo-free zone in place of the normal central renal
echoes. In addition, a linear echo-free zone extended from the medial aspect of the kidney to the true pelvis representing a dilated ureter (Fig. 7B). The correct diagnosis of hydronephrosis on the left could thus be made. Subsequent voiding cystography demonstrated free reflex on the right accounting for the dilatation. Retrograde pyelography demonstrated atresia of the distal left ureter. Similarly, we have been able to identify a dilated proximal ureter leading into an echo-free zone in a patient with obstruction to the upper pole of a duplicated system [2]. When a dilated ureter is not definitely identified in the region of the kidney, frequently due to overlying structures including bone and gas-containing bowel, the true pelvis should be searched for the presence of a dilated ureter (Fig. 7C). Identification of a dilated ureter in the true pelvis will again lead to the correct diagnosis of obstructive uropathy. In addition, the bladder should be searched for the presence of a ureterocele, which will typically appear as an echo-free zone in the bladder related to its posterior wall [5]. Since ureteroceles may be obscured by contrast media at urography, this ultrasound observation may be of great aid in reaching the correct diagnosis.
FIG. 6. Longitudinal parasagittal section through the liver and right kidney. There is an echo free lobulated zone in the iter of the right kidney representing gross hydronephrosis (H).

FIG. 7A. Excretory urogram on a four-year-old girl showing dilatation of the right collecting system and ureter and no excretion on the left.
FIG. 7B. Longitudinal section of the abdomen at the level of the mid-claviular line. The patient's head is to the right and feet are toward the left. There is gross dilatation to the left collecting system (H) and in addition a dilated ureter (u) is seen extending from the collecting system toward the true pelvis. These findings are characteristic of hydronephrosis due to ureteral obstruction.

FIG. 7C. Transverse section through the true pelvis. The bladder (B) is seen as an echo free structure in the anterior true pelvis. There is mild dilatation to the right ureter (R) and marked dilatation to the left ureter (L) both of which are identified posterior to the bladder. Subsequent uroradiologic studies demonstrated that there was obstruction to the left ureter and that there was reflux from the bladder into the right ureter.
Renal Mass Lesions

Ultrasound can play a central role in the identification and characterization of renal mass lesions [5,6,7,8]. In equivocal urograms, ultrasound is one non-invasive modality which can be used for further evaluation. When a definite lesion is appreciated at urography, ultrasound can then be used to differentiate cystic from solid masses. The features of a renal cyst vs. a renal tumor on grey-scale ultrasonography are shown in Table 2. Our grey-scale ultrasound studies are performed at a relatively high gain. Cysts are echo-free and have smooth walls. The ultrasound beam is transmitted through a cyst very well as compared with the attenuation that occurs with most renal tumors. A lesion seen protruding from the left kidney is echo-free, well marginated, and shows no evidence of attenuation of the echo beam (Fig. 8). The A mode of this lesion is shown in Fig. 9. The height of the echoes through the cyst is demonstrated and it can be seen that the lesion is relatively echo-free and that the posterior wall of the lesion is higher than the anterior wall in amplitude indicating good through transmission. In contrast, a transverse section of a patient with lymphoma of the right kidney is shown in Fig. 10. On this section the entire visualized kidney is replaced by tumor. There is an irregular echo pattern throughout the kidney and the normal central pelvicalyceal echo complex is not appreciated. The A mode demonstrated high level echoes through the lesion and decreased echo amplitude of the back wall as compared to the front wall.

Computerized axial tomography (CT) offers an additional non-invasive method of investigating renal mass lesions. This imaging modality is able to produce X-ray body sections by the use of an X-ray tomographic scanner and image reconstruction by means of a computer. The various densities are displayed as shades of grey. The X-ray attenuation properties of a lesion in question can be quantified. With contrast enhancement, cysts are of water density and do not enhance [9,10]. Computerized axial tomography thus is an alternative diagnostic modality which can be used to further clarify the nature of a renal mass lesion. For example, Fig. 11 shows a CT scan of the same patient whose ultrasound is shown in Fig. 8. The cyst in the left kidney is clearly shown.

When a cyst is identified by ultrasonography, renal cyst puncture and cellular analysis permits the exclusion of a malignancy. Simple renal cysts have clear fluid with negative cytology. A renal cyst should not contain fat [11] and the lactic dehydrogenase (LDH) is typically less than blood level [12]. Higher LDH levels indicate only that the lesion is not a simple renal cyst and occur with renal tumors and with other lesions such as hematomas or hemorrhage into a renal cyst. The properties of a cyst aspirate are summarized in Table 3.

Although either ultrasound or CT scanning may be used in the differential diagnosis of a mass identified on excretory urography, ultrasound is more commonly chosen. It is more rapid than CT scanning, involves no ionizing radiation and requires less expensive equipment. However, as noted above, CT scanning can be an important study when the ultrasound is equivocal. The basic schema recommended at the Yale-New Haven Hospital for the diagnosis of renal mass lesions is shown in Table 4. The ultrasound study is performed on any mass identified at urography. If a renal cyst is diagnosed by ultrasound, cyst puncture will confirm that this is a simple renal cyst. If the cyst aspirate is abnormal, unless purulent material is obtained indicating an abscess, angiography or surgery is the next step depending upon the analysis of the cyst fluid. When an equivocal ultrasound scan is obtained, nephrotomography and computerized tomography may be used to further differentiate cysts
TABLE 2
Renal Cyst vs. Renal Tumor

| Renal Cyst                  | Renal Tumor                  |
|-----------------------------|------------------------------|
| Echo-free                   | Internal echoes              |
| Smooth walls                | Irregular margins            |
| Good transmission           | Attenuation                  |

FIG. 8. Longitudinal section through the left kidney (k). A small cyst (c) is seen protruding from the kidney.

from tumors. When a solid lesion is noted at ultrasound, it is very helpful to do angiography both to identify the vessels feeding the lesion for the surgeon and to confirm the solid nature of the mass.

An additional pitfall in the evaluation of the left kidney for renal masses occurs when an ectopic left kidney is present or when there is only a solitary right kidney. In these situations the anatomic splenic flexure occupies the left renal fossa as shown by Meyers [13] and by Moscatello and Lebowitz [14]. The anatomic splenic flexure is that portion of the colon which is normally lateral and posterior to the spleen. The medial position of the anatomic splenic flexure in the left renal fossa can be recognized on barium studies or on plain films, particularly with the patient prone. On barium enema, barium will flow into the renal fossa and then out into the remainder of the splenic flexure. This is in contrast to the normal flow of barium into the laterally placed anatomic splenic flexure and then in a superor-medial direction. When fluid filled, the anatomic splenic flexure may appear as a cystic mass in the renal fossa on ultrasound examination, and when it has fecal material within it, it may mimic a solid mass [15]. Therefore, it is important to attempt to identify the position of the anatomic splenic flexure on radiologic studies and to use this information in interpreting the sonogram.

Renal Transplant Evaluation

The ultrasound examination is independent of renal function and of renal blood
FIG. 9A. Transverse section through the cyst and kidney of the same patient as shown in Fig. 8. The solid line demonstrates the plane from which the A-mode was obtained.

FIG. 9B. A-mode in the plane of the solid line shown in A. The height of the echoes along the path of this line are represented by vertical deflection. The cyst is the echo free area. Note that the anterior wall (arrow) is lower in intensity than the posterior wall (arrowhead) of the cyst.

FIG. 10. Transverse section of the right kidney in a patient with known lymphomatous involvement of the left kidney. The entire kidney (K) is replaced by tumor. Instead of the normal echoes there are irregular echoes scattered throughout.
FIG. 11. CT scan of the same patient whose ultrasound is shown in Fig. 8. There is contrast enhancement and the cyst (arrow) is seen protruding from the left kidney. The cyst is of different density than the rest of the kidney.

**TABLE 3**

| Renal Cyst | Cyst Puncture |
|------------|---------------|
| Fluid      | Clear         |
| Cytology   | Negative      |
| LDH [12]   | Less than blood level |
| Fat [11]   | None          |

**TABLE 4**

Evaluation of Renal Mass Lesions

Excretory Urography: Renal Mass

- Ultrasound
  - Cyst
  - Equivocal
    - Nephrotomography and/or CT
      - Simple Cyst
        - Abnormal
          - Abscess
          - Angiography
          - Surgery
        - Cyst Puncture
      - Solid or Complex
        - Tumor
        - Cyst
        - Other
flow and is a useful complementary modality to other imaging studies in the evaluation of renal transplants. Pelvic fluid collections such as lymphoceles, urinomas, or hemotomas are typically recognized as echo free masses within the true pelvis [16]. An increase in renal size is generally noted with rejection [17] and this can be easily appreciated by ultrasound examination [18]. Hydronephrosis is an additional finding that can readily be recognized and in addition can be followed sequentially without exposing the patient to additional ionizing radiation [19]. Nuclear medicine studies and excretory urography are complementary to ultrasound in the evaluation of renal transplants in that they provide physiologic parameters.

Renal Infection

A renal abscess can be identified as a mass on the ultrasound study. This mass may appear as homogeneous fluid or may have echoes scattered within it (a so called “complex” lesion). At times we have observed an abscess to be initially echo containing but subsequently to become more homogeneous and echo free with treatment. A perinephric abscess, as well as other perinephric collections such as a hemotoma, typically appears in transverse section as an echo free zone around the renal margin [2]. On longitudinal section, since perirenal abscesses tend to gravitate inferiorly [20], the abscess will appear as an echo-free collection around the lower portion of the kidney and extending inferiorly (Fig. 12). We have had the opportunity to examine several patients with tuberculosis of the kidney and the echo pattern which is observed varies with the pathology which is present. Small tuberculous cavities will not be appreciated. Abscesses in the parenchyma due to tuberculosis will appear similar to those described above. If tuberculosis has resulted in stricture formation with subsequent hydronephrosis the appearance on ultrasound will be that of hydronephrosis.

Renal Cystic Disease

Ultrasound findings in several of the renal cystic diseases have been described. In adult polycystic kidney disease the kidneys are typically large at ultrasound and cysts will be seen in the parenchyma [21]. Ultrasound is also an excellent modality for the identification of hepatic cysts [1,22] and since approximately one-third of the patients with adult polycystic kidney disease will also have cysts in the liver this finding is significant. The combination of large, cystic kidneys and cysts in the liver is a characteristic pattern for adult polycystic kidney disease. At the Yale-New Haven Hospital, we have been engaged in a prospective study of imaging modalities in adult polycystic kidney disease. Both ultrasound and computerized axial tomography have demonstrated cysts in the kidneys and cysts in the liver of adults with known polycystic kidney disease [23]. In addition, the asymptomatic progeny of these patients have been examined with both high-dose nephrotomography and grey-scale ultrasonography. Renal cysts have been demonstrated by ultrasonography which were not seen on nephrotomography.

Two patterns have been described in multicystic dysplastic kidney [24]. Where multiple cysts are present, many fluid-filled areas with septae are seen. When a single cyst predominates, a large echo-free area may be noted, and this may be difficult to distinguish from hydronephrosis. We have also examined patients with medullary cystic disease of the kidney and congenital hepatic fibrosis with tubular ectasia. There are indications that ultrasound may play a useful complementary role in the diagnosis of these diseases [25].
The Adrenal

Adrenal masses may be appreciated either predominately above or medial to the kidney. Ultrasound permits identification of these lesions and determination of their solid or cystic nature. Calcification produces very high-level echoes. A right pheochromocytoma is shown in Fig. 13A as a solid mass extending medial to the right kidney. Angiography confirmed that this was a vascular adrenal tumor (Fig. 13B).

Clarification of Pelvic Mass on Excretory Urography

Ultrasound is a rapid technique which can be used during the course of an excretory urogram or immediately thereafter to further clarify a confusing finding. For example, a thirty-nine-year-old woman had an excretory urogram because of a high creatinine. In addition to the poor function at urography, a soft-tissue pelvic mass appeared to be present which could be due to a pelvic tumor, distended bladder or significant ascites (Fig. 14A). A cystogram performed during the course of the excretory urogram demonstrated that the density in the true pelvis was not due to a distended bladder (Fig. 14B). Ultrasound examination demonstrated that the density in the true pelvis was ascitic fluid which shifted with changes in position (Fig. 14C). However a “pelvic mass” was noted. On the longitudinal section (Fig. 14D) there is a one centimeter solid mass protruding from the uterus most likely a pedunculated fibroid. The ultrasound examination of the kidneys demonstrated no evidence of hydronephrosis or perirenal masses. This case typifies the use of ultrasound to rapidly clarify a difficult problem on excretory urography without the use of ionizing radiation.

The Lower Urinary Tract

Ultrasound examination is of value in the examination of the lower urinary tract in
FIG. 13A. Longitudinal section through the right kidney with the patient prone. The head is toward the right and the feet are toward the left. An echo containing mass (p) is seen anterior and superior to the kidney. This is a typical location for an adrenal lesion.

FIG. 13B. Angiography in the same patient as Fig. 13A demonstrates a vascular right adrenal mass. At surgery this proved to be pheochromocytoma.

that it can demonstrate lesions in and around the bladder. The fluid filled bladder is used as a “window.” A typical bladder tumor appears as a solid mass within the bladder [25]. Fig. 15 shows an enlarged prostate appearing as a solid mass at the neck of the bladder. There is irregularity in the bladder where it abuts the prostate
FIG. 14A. Ten minute film from the excretory urogram on a thirty-nine-year-old woman with renal failure. There is no appreciable excretion from the kidneys. A density is seen in the true pelvis which might be due to either ascites, a distended bladder, or possibly a pelvic mass.

FIG. 14B. Cystogram performed during excretory urography demonstrates that the density in the true pelvis is not the bladder.
FIG. 14C. Longitudinal section through the true pelvis. There is ascites as can be appreciated by the large echo free zone encompassing most of the true pelvis. The uterus (arrow) is seen in the mid-portion of the true pelvis and is normal in appearance. It is suspended by the broad ligaments (arrowheads).

FIG. 14D. Longitudinal section through the true pelvis. The head is to the right and the feet are to the left. The uterus (arrow) is once again seen resting in the ascitic fluid. There is a one centimeter solid mass protruding from the superior aspect of the uterus (arrowhead) almost certainly representing a pedunculated fibroid. The echo containing structures cranial to the uterus are generated by gas filled bowel.

consistent with prostatic carcinoma. The approach to prostatic lesions by use of a transducer placed in the rectum is an area of current investigation in some centers [26].
FIG. 15. Longitudinal and transverse scans of the true pelvis of a man with prostatic carcinoma. The bladder (b) is seen an echo free structure anterior to the echo containing prostate (p). The prostate is enlarged and there is an irregular interface between bladder and prostate indicating involvement of the bladder wall by the prostatic tumor.

DISCUSSION

Ultrasound should be viewed as a complementary examination to the standard imaging modalities. The highest accuracy is attained when the previous studies such as the radioisotope examination, the computerized axial tomogram, the excretory urogram, and the retrograde pyelogram are available for review when interpreting the ultrasound study. In combination with the clinical history, this provides guidance for further studies or provides a final diagnosis. Ultrasound may serve as a primary imaging study in patients with a history of significant contrast media reaction or when renal failure prevents optimal examination of the urinary tract by excretory urography. In addition, ultrasound has the potential to serve as a screening study in patients who may have a genetic cystic disease. Undoubtedly with future improvement in ultrasound resolution and with further experience with this modality, other applications of ultrasound in the diagnosis of urinary tract pathology will be identified.

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