minor calyces viewed on standard anteroposterior radiographic images can appear as if they were placed in the pelvis or a major calyx. Thus, this anatomic detail must be considered in cases of stones that do not alter renal function and can appear as if they are in the renal pelvis or a major calyx. In this situation, a complementary radiologic study with lateral and oblique films must be performed to determine accurately the position and extent of the stones. When a stone is located in a perpendicular minor calyx, its removal presents additional difficulties for percutaneous nephrolithotomy (PCNL). Direct access into the calyx containing the stone is easy; nevertheless, it involves a puncture without consideration of the arterial and venous anatomic relationships to the collecting system, which carries a high risk of injuring a vascular structure. Therefore, in cases of stone in such calyces, safe access, techniques and instruments should be used.

Identifying the Posterior Calyx: The Big Dilemma

An important consideration for percutaneous renal surgery is the determination of the anteroposterior orientation of the calyces, because access (from the typical posterior or posterolateral approach) into a posterior calyx allows relatively straight entry into the rest of the kidney, whereas percutaneous puncture of an anterior calyx requires an acute angulation to enter the renal pelvis, which may not be possible with rigid instrumentation.

Investigators have attempted to differentiate calyces as anterior or posterior solely on the basis of their medial or lateral orientation as seen on IVU. The available anatomical references on this aspect are contradictory, confusing and incomplete. In 1901, Brodel studied corrosion casts of 70 cadaveric kidneys. He depicted the anterior calyces as medial and posterior as lateral. Hodson, in 1972, described exactly the opposite, i.e. the anterior calyces located laterally and posterior calyces located medially. Then, in 1984, Kaye and Reinke measured calyceal angles from the axial CT images. They concluded that the Brodel pattern is seen in 69% of right kidneys while 70% of left kidneys have a Hodson pattern.

Sampaio et al studied 140 endocasts and found that the anterior calyces are lateral in 28%, posterior calyces are lateral in 19%, and in 53% endocasts the anterior and posterior calyces had varied positions, superimposed or alternately distributed. He found that the calyceal orientation was region dependent. The typical anterior and posterior pattern of the calyces is seen only in the middle pole. The lower pole has this arrangement in only 58% cases while the upper pole almost uniformly has a compound calyceal system. This implies that in the lower and upper pole the calyces are dominantly oriented in the direction of their respective poles.

Miller studied detailed renal calyceal anatomy obtained from *in vivo* three-dimentional computerized tomography (CT) renderings.[5] The primary plane of the upper pole calyceal group was mediolateral (ML) in 95% of kidneys and a combination of anteroposterior (AP) and ML in 5%. The middle calyceal group had a primary plane of AP in 100% of kidneys. The primary plane of the lower pole calyceal group was AP in 95% of kidneys, ML in 3% and a combination of AP and ML in 2%.

Computerized tomography (CT) reconstruction and assessment preoperatively helps in defining the calyceal anatomy and planning the calyceal entry (Fig. 1.3). A well-studied IVU also helps in near accurate estimation of the posterior calyx (Fig. 1.4).

Upper Polar Access

Miller et al found that in the upper pole, the primary plane of the calyces in the upper pole was medial/lateral and generally neutral relative to the anteroposterior (AP) axis of the kidney. As the upper pole is more posterior in the prone position, access via any calyx would provide a working tract that parallels half of the kidney. After the anterior segmental arteries and the posterior branch of the renal artery enter the renal parenchyma, they divide into interlobar arteries, which are also called infundibular arteries owing to their course adjacent to the calyceal infundibula of the renal collecting system. At the cortico-medullary junction, near the base of the renal pyramids, each interlobar artery usually divides into two arcuate arteries that run along the renal pyramid. The next division is into the interlobular arteries, which run along the outer surface of the renal pyramids and are derived at right angles from the arcuate arteries. The final divisions, the afferent arterioles of the glomeruli, come off the interlobular arteries in the peripheral renal cortex. Each renal arteriole is an "end-artery", meaning that each cell in the kidney derives its blood supply from one arteriole. For this reason renal arterial vascular injury must be avoided to prevent loss of renal function. The potential for arterial injury is least in the Brödel line, which is an avascular plane approximately at the lateral margin of the kidney (Figs 1.7 and 1.8), extending from the superior apex of the kidney (limited by the circulation of the apical anterior segmental artery) to the lower pole of the kidney (limited by the circulation of the lower anterior segmental artery).

Regional Vascular Anatomy of the Kidney

Sampaio analyzed 82, 3D polyester resin corrosion endocasts of the kidney collecting system together with the intrarenal arteries, and 52 endocasts of the kidney collecting system together with the intrarenal veins, obtained according to the injection-corrosion technique.

Puncture is most dangerous through the upper pole infundibulum because this region is surrounded almost completely by large vessels (Table 1.1). Infundibular arteries and veins course parallel to the anterior and posterior aspects of the upper pole infundibulum. Injury to an interlobar (infundibular) vessel was a common consequence of puncturing the upper pole infundibulum (67% of kidneys); the injured vessel was an artery in 26% of those cases. The most serious vascular accident in upper infundibulum puncture is lesion of the posterior segmental artery (retropelvic artery). This event may occur because this artery was crossed by and is related to the posterior surface of the upper infundibulum in 57% of the endocasts.

In the inferior pole, a collar-like venous anastomosis around the minor calyces infundibula (calyceal necks) is often found. Puncture through the lower pole infundibulum, therefore, also risks injury to a venous arcade.[2]

Relationship of kidneys to the diaphragm, ribs and pleura.

The kidneys lie on the psoas and quadratus lumborum muscles. Usually, the left kidney is higher than the right kidney, with the posterior surface of the right kidney crossed by the 12th rib and the left kidney crossed by the 11th and 12th ribs. The posterior surface of the diaphragm attaches to the extremities of the 11th and 12th ribs. Close to the spine, the diaphragm is attached over the posterior abdominal muscles, and forms the medial and lateral arcuate ligaments on each side. In this way, the posterior aspect of the diaphragm (posterior leaves) arches in a dome above the superior pole of the kidneys, on each side. Therefore, when performing an intrarenal access by puncture, the endourologist may consider that the diaphragm is traversed by all intercostal punctures, and possibly by some punctures below the 12th rib.

Stening and Bourne have discussed in depth the anatomic considerations in the supracostal approach for renal surgery.[7] The lower limit of the parietal pleura crosses the 12th rib obliquely at its midpoint such that the lateral half of the rib is uncovered by the pleura. In the midscapular line, the visceral pleura is in relation to the 10th rib, while the parietal pleura is at the level of the 12th rib. The parietal and visceral pleura ascend cranially and laterally on the ribs, and further

- Puncture of the lower pole may be slightly more difficult as the freely mobile lower pole moves away from the needle and dilators. Also, the lower pole tracts tend to be longer and more oblique, making stone removal from upper calyces with rigid instruments may be more difficult than the converse. Due to the posterior tilt of the upper pole of the kidney, the lower pole does not offer assured access to the upper pole.

Upper Calyceal Access: Subcostal or Supracostal

The upper portions of both the kidneys are located anterior to the posterior portion of the 11th and 12th ribs. A review of 90 normal supine intravenous urograms during full expiration noted that 85% of upper renal calyces are located above the 12th rib.[5] In the prone position, further cephalad movement of the kidney occurs in 80% of patients.[6]

Subcostal access is the safest route to the kidney because pleural injuries are rare with entry below the 12th rib. Nonetheless, if entry directly above the 12th rib (11th intercostal space) provides the best access to the optimal calyx, then the benefit generally exceeds the risk.

Entry above the 11th rib, however, has a greater potential for pleural and even lung injury, so when the best access calls for a direct puncture above the 11th rib, additional maneuvers could be considered to displace the kidney inferiorly. These include cephalad tilt of a subcostal access sheath placed into a lower calyx and attaining access during full inspiration. Smith et al[7] described the renal displacement technique wherein initial placement of a sheath or dilator is performed via a lower or midcalyx in order to allow for torque of the kidney downward. This can be held by an assistant while upper calyx puncture is performed via a subcostal route. This technique however mandates an unnecessary second tract. Another alternative is to angle the upper calyceal access tract cephalad from a subcostal skin entry site. This approach provides limited access to the rest of the kidney and traverses more of the renal parenchyma obliquely with increased chances of bleeding.[8] All of these alternatives can result in severe angulation and torque on the renal infundibula with damage to the infundibular vessels.

Stening and Bourne have discussed in depth the anatomic considerations in the supracostal approach for renal surgery.[9] The lower limit of the parietal pleura crosses the 12th rib obliquely at its midpoint such that the lateral half of the rib is uncovered by the pleura. In the midscapular line, the visceral pleura is in relation to the 10th rib, while the parietal pleura is at the level of the 12th rib (Fig. 2.3). The parietal and visceral pleura ascend cranially and laterally on the ribs, and further rise in deep expiration. Thus, a puncture made lateral to the midscapular line, below the 10th rib, in deep expiration would almost always prevent damage to the visceral pleura (Fig. 2.4A).

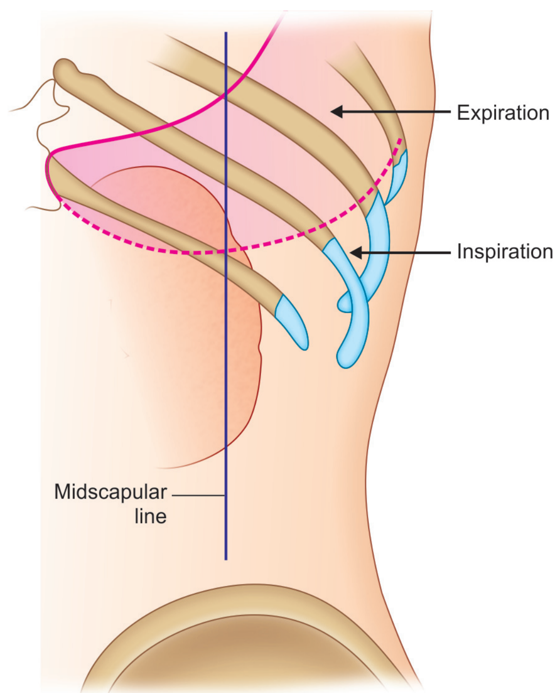

Fig. 2.3: Parietal pleura during phases of respiration: Diagrammatic representation (Stening and Bourne)

ascertained by the surgeon and adjustments made accordingly. The easiest way to determine this would be to place another needle on the skin surface over the target calyx or correlate with the spine. If the calyx is between the two needles or between the spine and the puncture needle, then the puncture needle is deep and should be adjusted superficially. If the target calyx is below the two needles or below the puncture needle and the spine, then the puncture needle is superficial and should be adjusted toward the depth.

Hybrid Technique[19]

- The three most important things needed to achieve a successful percutaneous renal puncture are the site of skin entry, the angle of entry and the depth at which the puncture is achieved.
- Determining the correct point of skin puncture is important in the triangulation technique because a skin puncture that is too medial or lateral to the desired optimum point of entry would result in a tract of variable length and angle of entry in the calyx. This would interfere with proper access and would cause excessive torque on the parenchyma during maneuvering of the rigid nephroscope in the pelvicalyceal system. To avoid injury to the colon, the puncture should be medial to the posterior axillary line but not too medial as it would traverse the paraspinal muscle causing increased postoperative pain and would probably be directly on the renal pelvis without traversing the renal parenchyma. The puncture that is too close to the rib may injure the intercostal nerve and vessels and hence is to be avoided.
- Sharma described the technique of determining the site of skin puncture, which amalgamates the advantages of both the bull's eye and triangulation technique and hence is called the hybrid technique. With the C-arm at 0°, the site of skin corresponding to the target calyx is marked as point A. The C-arm is then rotated 30° towards the surgeon. The point on the skin corresponding to the target calyx and forming a bull's eye with the needle is marked as point B. In the bull's eye technique we take a puncture at the point B. However, in the triangulation technique, the puncture is along the stone axis in alignment with the infundibulum. If we take the target calyx as the center of a sphere, then we have an imaginary circle on the skin where the point A is the center of the circle. The distance from point A to B will be the radius of the circle. The radius remains the same irrespective of the direction in which it is measured from the center of the circle. Thus, when we take a line along the stone axis where we intend to take a puncture—the site of skin puncture is marked using this principle. This means that the point B1 is marked on the skin such that the distance from point A to B1 is equal to the distance between A to B, i.e. the radius of a circle with the target calyx being its center. B1 is the site of entry on the skin.
- The angle of puncture: In the bull's eye technique, the angle at which the needle is seen as a dot is the angle at which the puncture is made. The hybrid technique utilizes this principle. With the needle at point B and the C-arm rotated 30° towards the surgeon and the needle forming the bull's eye; the angle that the needle makes with the skin surface is measured using a protractor. One needs to take care that the protractor is held parallel to the operating table. Using the principle of sphere and circle; if we are hitting the calyx by using the triangulation technique from the point B1—the angle of puncture would be the same with probably variations of 1–2° due to the not so perfectly flat contours of the body surface.
- The third component of the hybrid technique is to determine the depth of