Review Article

Techniques for fluoroscopy-guided percutaneous renal access: An analytical review

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ABSTRACT

Percutaneous renal access is a key step for a successful percutaneous nephrolithotomy. It involves the use of fluoroscopy, ultrasonography, or a combination of both. Over the years, various techniques have been proposed for fluoroscopy-guided access, and this article reviews the different techniques along with the anatomical principles for fluoroscopy-guided percutaneous renal access. A literature search was performed using "PubMed" for relevant literature describing the various techniques for fluoroscopy-guided percutaneous renal access. Each technique was analyzed in regard to how it describes selecting the skin site for puncture and determines the angle and depth of puncture. The advantages, limitations, and variations of these techniques were also studied. Each technique has its advantages and limitations. No study has compared all the techniques either *in vivo* or *in vitro*. Only a comparative study would establish the superiority of one technique over the other. Until this is done, endourologists should be well versed with the existing techniques.

INTRODUCTION

Since its first description in 1942 by Rupel Brown and then the first extraction of calculus in 1976 by Kinn *et al.*,[1] percutaneous nephrolithotomy (PCNL) has come a long way. In the last decade, there has been rapid strides made by medical industry with nephroscopes of various sizes being added to a urologists armamentarium resulting in development of Mini PCNL, Ultra Mini PCNL, and Microperc.[2] However, one thing which has not changed is the importance of a proper access for a successful PCNL. A variety of strategies and technologies are being evaluated to achieve good access and also help the surgeon to decrease the learning curve. This is especially so in case of fluoroscopic-guided percutaneous renal access. Studies have shown that at least 60 cases are needed to achieve a certain degree of expertise.[3] This steep learning curve is easy to comprehend. Fluoroscopy provides a two-dimensional picture, and the surgeon is visualizing and attempting to enter a three-dimensional space with its help.[3,4] He needs to maintain the direction of the needle in either the mediolateral/oblique plane while making the adjustments in the other plane.

A number of techniques have been described to facilitate this process, and with time, a number of modifications of the original techniques have also been described. This possibly indicates that there are certain lacunae in each of the techniques.

This review describes the various techniques used for fluoroscopy-guided percutaneous renal access. It also describes how fluoroscopy is used to determine the correct calyx for access and the anatomical principles behind it.

WHICH CALYX TO PUNCTURE?

An ideal calyceal access is one that facilitates complete clearance of the calculus with no or minimal complications.

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This principle has led to the widespread acceptance that a posterior calyx should be punctured.[5,6] Credence to this has come from the anatomical studies by Sampaio *et al.*[7] The question is how to identify the posterior calyx with the patient in prone position? The kidneys lie on the posterior abdominal wall against cone-shaped psoas muscle. Their longitudinal axis is parallel to the oblique course of the psoas at an angle of 13°–30° to the midline and due to a dorsal tilt, the upper pole is more medial and posterior than the lower pole. Due to the anterior rotation of the hilar region on the psoas muscle by about 30°, the lateral aspect of the kidney is posterior to the medial aspect. Additionally, the kidneys are angled 30°–50° behind the frontal plane resulting in the upper pole being posterior to the lower pole.[8]

The classical teaching that an ‘end-on’ calyx is the posterior calyx has been discarded from the evidence coming from studies of the pelvicalyceal system using computed tomography.[9,10] In prone position, the pelvis and the lower pole fall anteriorly as compared to the upper pole.[11,12] Studies by Sampaio on endocasts have shown that the posterior calyces are lateral in 19% while the anterior calyces are lateral in 28% cases. Interestingly, they found that in 53% endocasts studied, the anterior and posterior calyces had variable positions and were either superimposed or alternately distributed.[8] These studies also showed that the calyceal orientation was region dependent. The classical anterior and posterior arrangement of the calyces was seen only in the middle pole. The upper pole almost always had a compound calyceal cystem. The typical anterior -posterior arrangement of calyces was seen in only in 58% cases in the lower pole. What this indicates is that in the upper and lower poles, the calyces are dominantly oriented in the direction of their respective poles. Accordingly, the upper pole calyces ought to be oriented posteriorly, a fact confirmed by computed tomography studies.[9,10] The calyces in the upper pole are thus all posterior calyces with the calyx having a medial or lateral orientation. Anatomical studies emphasize that the lateral calyx of the upper pole should be punctured to avoid injuring the posterior segmental artery.[13] The arrangement of calyces is most complex in the lower pole. Eisner *et al.* found that if the lower pole has two calyces, than the more lateral calyx is likely to be a posterior calyx. If the lower pole has three calyces than the second calyx from the medial aspect is likely to be more posteriorly oriented. They also found that often, these calyces are less anterior than the other calyces and may not be absolutely posterior.[14]

This concept of puncturing the posterior calyx to avoid a major vascular injury has recently been questioned by studies by Kallidonis *et al.*[15] They found an infundibular puncture safe, especially for the midpole. However, till date, this has been a single-center study which has still not found widespread acceptance among urologists.

IDENTIFYING THE POSTERIOR CALYX ON FLUOROSCOPY

Anteroposterior radiography is unable to determine the desired posterior calyx in most of the scenarios and; hence, additional maneuvers are needed.[16] In the prone position when contrast is instilled in the pelvicalyceal system, it will fill the dependent anterior calices first. The posterior calices are filled later and appear less dense.[5] At times, 5–10 ml of air can be injected via the ureteric catheter to identify the posterior calices. Air being lighter will preferentially enter the posterior calices when the patient is prone.[5,17] If, despite these maneuvers, the dilemma to identify the suitable posterior calyx persists, the movement of the C-arm can be utilized to identify the posterior calyx. In the prone position, the posterior calyces will move in the direction opposite to that of the image intensifier on the C-arm. Thus if the C-arm is rotated toward the surgeon, then the posterior calices will appear to move away and shorten and appear more medially placed. Vice versa, if the C-arm is rotated away from the surgeon, then the posterior calices appear elongated and appear laterally placed.[18]

WHAT IS AN IDEAL PUNCTURE?

Bernardo and Silva[19] have described that for a safe, complication free surgery, percutaneous renal access must meet the following conditions: it should be (1) from a posterolateral position, (2) through the renal parenchyma, (3) toward the center of a calyx posterolaterally, and (4) toward the center of the renal pelvis. For achieving percutaneous renal access, a surgeon has to decide the skin site for puncture, decide the trajectory, i.e., the angle to the desired calyx and determine the depth at which the calyx would be punctured.

The European Society of Uro-Technology have described various basic techniques for fluoroscopy-guided percutaneous renal access.[20] They are broadly divided into those where the C-arm is fixed or can be moved in different directions, i.e., biplanar access and its variations [Figure 1].

BULL’S EYE TECHNIQUE

Determining site of skin puncture

With the C-arm perpendicular to the patient, i.e., at 0°, the calyx to be punctured is determined. Then, the C-arm is rotated 30° toward the surgeon and the site on the skin where the target calyx is seen is marked and the puncture is made from this site.[5,6]

Determining the angle of puncture

Once the site of skin puncture is determined, the needle is held using a custom-made needle holder or a hemostat in a way that it is seen as a dot on the fluoroscopy monitor; hence, the name Bull's eye or Eye of the Needle technique.[6] This determines the trajectory of the needle. Very often, in order to have an end on appearance of the target calyx situated in the upper pole a tilt of 5°–10° in the cranial direction is needed. For the lower pole, a similar tilt in the caudal direction is needed.[5]

Determining the depth of puncture

The needle is advanced keeping the angle as determined previously, and the loss of resistance is usually an indication that the calyx is punctured. Bringing the C-arm to 0° does not give a proper indication of the depth, rather it should be moved away from the surgeon by few degrees.[5]

Variations of the technique

It is often the muscle memory that comes with experience, which helps in maintaining the correct needle alignment.[21] To maintain the needle alignment, Bilen *et al*. have described the use of an in-line laser pointer which is attached within the field of the receiving head of the C-arm fluoroscopy unit. This serves as a guide for renal access.[22] Ko and Razvi described a further modification in which a laser positioning device is fixed on the C arm. This results in the laser beam being focused on the hub of the needle continuously and hence the trajectory of the needle is maintained.[23] The aim of these modifications has been to help maintain the correct needle alignment and consequently decrease fluoroscopy exposure. A mini access guide has been described by Chowdhury *et al*. with the aim to maintain needle stability and thus achieve better puncture efficacy.[24]

Advantages of the bull's eye technique

The site of skin puncture is determined, and the angle of puncture is determined with a single rotation of the C-arm toward the surgeon.

Drawbacks

The needle needs to be maintained in the correct angle. The determination of depth needs rotation of C-arm away from the surgeon. The trajectory of the puncture is toward the center of the calyx, while in the mid pole, it may also be toward the center of the renal pelvis; it is not so if the puncture is made in the upper or lower pole calyx [Figure 2]. This can lead to torque on the renal parenchyma when the rigid nephroscope is maneuvered in the pelvicalyceal system and thus increases the risk of hemorrhage besides decreasing the chances of complete stone clearance.[25] This difficulty would be significantly more in cases with previous surgeries on the same kidney with consequent adhesions around it.

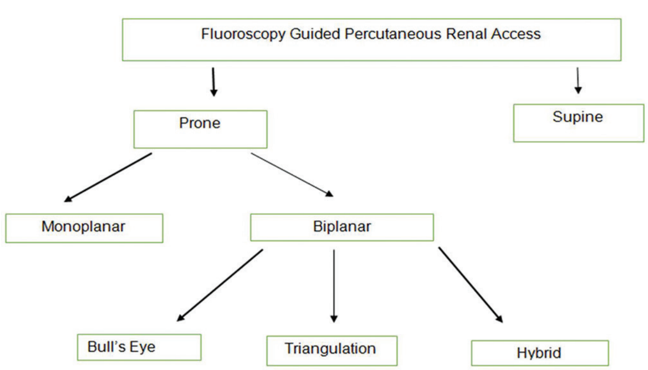

Figure 1: The various fluoroscopy-guided percutaneous renal access techniques

TRIANGULATION TECHNIQUE

Determining site of skin puncture

In this technique, the puncture is aligned in line with the infundibulum[6] [Figure 2]. Triangulation by definition means using two known points of reference to determine an unknown point. In PCNL, the unknown point to be determined is the target calyx while the two known points are the point on skin corresponding to the target calyx and the point of skin puncture. The classical description of triangulation technique gives principles but no definitive guidelines for determining the skin site for puncture.

The puncture should be medial to the posterior axillary line to avoid injury to the colon, but too medial a puncture should be avoided as it would traverse the paraspinal muscles, leading to increased postoperative pain. Hence, most urologists would determine the line of puncture along the axis of the infundibulum with the C-arm at 0° and determine the site of skin puncture few centimeters away from the target calyx on this line.

Determining the angle of puncture

The site of skin puncture would determine the angle of puncture needed to puncture the target calyx. With the C-arm at 0°, the needle is brought in alignment with the target calyx to determine the mediolateral direction. Then, the C-arm is tilted 30° towards the foot end for an upper pole puncture or 30 ^{0} toward the head end for a lower pole puncture; The needle is adjusted in the anteroposterior

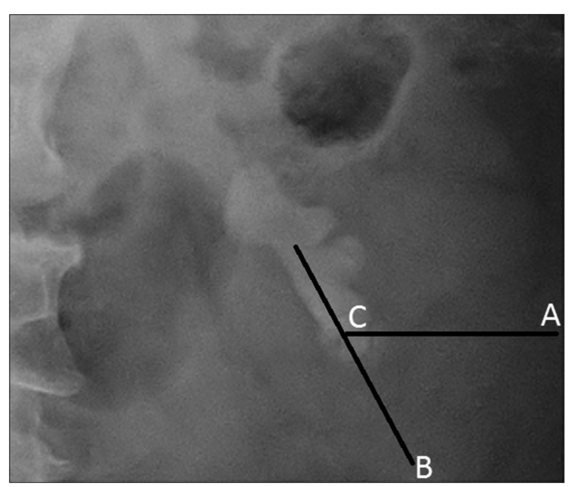

Figure 2: Line AC depicts the trajectory in a bull's eye technique. The line BC depicts the alignment of needle along the axis of the infundibulum

direction so that it aligns with the target calyx. This determines the trajectory of the puncture.[6,19] It is imperative that the needle is maintained in one plane while making the adjustments in the other plane. This step is associated with the steepest learning curve.[3,4] Furthermore, all these steps should be done in the same phase of respiration, usually end expiration.

Determining the depth of puncture

When the needle is being advanced, either it can go properly toward the target calyx or there can be deviation in mediolateral or anteroposterior direction. The mediolateral deviations are easy to judge by bringing the C-arm to 0°. The difficulty, especially during the learning phase, usually comes in the assessment of the depth which is done with the C-arm in the oblique position. Whether the needle is deep or superficial to the target calyx needs to be ascertained by the surgeon and adjustments made accordingly.[26] The easiest way to determine this would be to place another needle on the skin surface over the target calyx. If the calyx is between the two needles, then the puncture needle is deep and should be adjusted superficially. If the target calyx is below the two needles, then the puncture needle is superficial and should be adjusted toward the depth.[27]

Variations of the technique

Mues *et al.* have described a technique using a plumb and protractor in which the C-arm is rotated away from the surgeon by 30° for lower pole and by 20° for upper pole puncture. A plane of co-incidence is created between the C-arm and the needle. By this the need for manipulation of the C arm is avoided which can potentially decrease the time needed for the calyceal puncture.[28] However, it presumes a fixed angle of convergence. This may not necessarily be always true on account of the wide variations in the anatomy of the pelvicalyceal system due to the varying degrees of hydronephrosis. Li *et al.* have described a stereotactic localization system with specially designed instruments.[29] However they did not find this technique useful when the angle of puncture was <30° because the buttocks of the operator would be in the way. Furthermore, the authors selected the puncture point at a fixed angle of 45° from the skin to the stone. This again makes the principle of puncturing quite rigid as the variations in the pelvicalyceal anatomy may preclude adherence to such rigid angles. Basiri *et al.* have described a biplanar access technique in which the C-arm is rotated 30° toward the surgeon and then tilted 30° toward the foot end of the patient. However, this technique was used only for lower pole access and was used as an auxiliary method when attempt of puncture using the standard technique failed.[30]

Advantages

As the depth of advancement of the needle can be monitored continuously with the C arm in oblique position, the chance of the needle overshooting the target calyx and going too deep is avoided. Furthermore, the criteria of a successful puncture are fulfilled by triangulation technique.[19] The passage of rigid instruments in alignment with the infundibulum leads to less torque on the renal parenchyma and better maneuverability in the pelvicalyceal system, which could possibly contribute to better stone clearance.

Drawbacks

The maintenance of needle in one plane while determining the angle in the other plane is associated with maximum difficulty in the initial stages. This is so because both the planes cannot be seen at the same time on the fluoroscopy monitor.

HYBRID TECHNIQUE

The Hybrid[19,20] technique utilizes the advantages of both the bull's eye and the triangulation technique and uses mathematical principles to determine the site of skin puncture and angle of puncture and calculate the depth of puncture.

Determining Site of Skin Puncture

With the C-arm at 0°, the site on the skin corresponding to the target calyx is marked as point A. The C-arm is then rotated toward the surgeon, and the point on the skin corresponding to the target calyx is marked as point B. The distance AB is part of the arc of an imaginary circle whose center is the target calyx. If puncture is planned along the line of the infundibulum, then the point B1 is marked on this line in a way that the distance AB1 is equal to the distance AB[31] [Figures 3 and 4].

Determining the angle of puncture

With the C-arm rotated toward the surgeon and the needle is adjusted at point B in a way that it forms the Bull's eye, the angle is measured using a protractor [Figure 5]. Now, whether the puncture is made at the point B or is from point B1, the same angle of the needle is determined using a protractor and the trajectory of the needle is defined.[32] Care should be taken that all measurements are taken in the same phase of respiration, usually end expiration. Often, it is difficult to maintain the angle of needle and look at the angle on the protractor. Here, help from the assistant or the anesthesiologist can be taken.

Determining the depth of puncture

The point A, B, and the target calyx thus form an imaginary triangle and the distance AB forms part of the arc of an imaginary circle. Two techniques have been described to mathematically calculate the depth either using the law of sines with universal triangle solver app[32] or using the principle of calculating the radius from the circumference of a circle.[20] Thus, the surgeon can pre-calculate the depth of puncture.

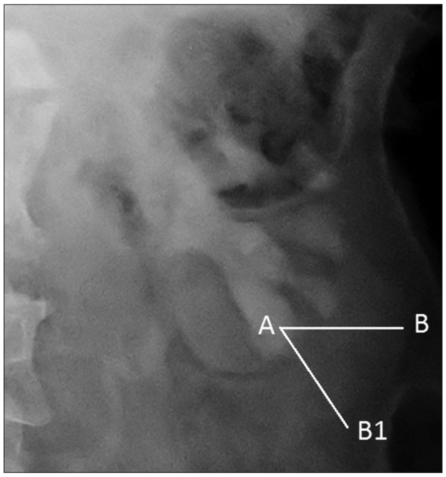

Figure 3: Determining the site of skin puncture in hybrid technique: The distance A to B1 is the same as the distance from A to B

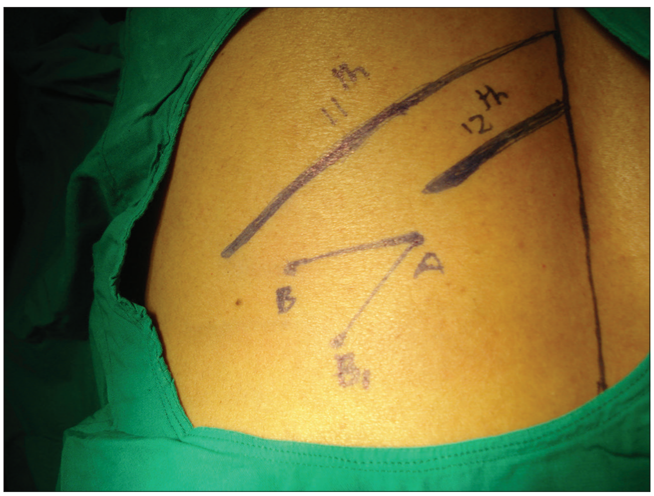

Figure 4: The points A, B, and B1 as marked on the skin with the patient in prone position

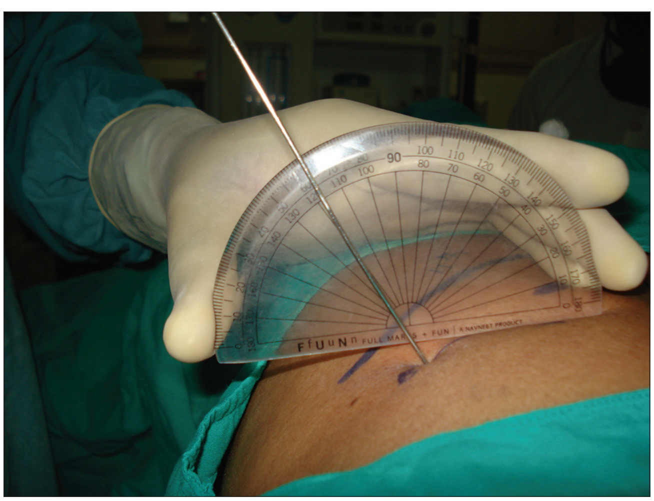

Figure 5: Determining the angle at point B using the protractor

Advantages

This technique describes all the three things which are needed for a puncture – site of skin puncture, angle of puncture, and depth of puncture.[33] Thus, it has the potential to decrease the learning curve in percutaneous renal access. Furthermore, as the angle of puncture is known, the dilators can also be passed at the same angle making dilatation easy, smooth, and associated with minimal risk of kinking the guide wire.

Drawbacks

The body contours are not perfectly flat, and hence, there would be a difference of couple of millimeters between the precalculated and actual depth.[32] Two methods of mathematical calculation of depth have been described for the hybrid technique, which of them is more accurate has not been ascertained by any study.

MONOPLANAR ACCESS

In this technique, access is achieved using a single fluoroscopic plane using a stable X-ray generator providing radiation perpendicular, i.e., at 0° to the patient.[34]

Determining site of skin puncture

This is done along the axis of the infundibulum; however, no guidelines have been described.

Determining angle of puncture

This is based on the surgeon's experience and the site of skin puncture, either close to or away from the target calyx, would make the angle more acute or oblique, respectively.

Determining depth of puncture

This again comes with experience as rotation of fluoroscopy monitor is not available to judge the depth of trajectory of needle. If urine is not aspirated, then increasing or decreasing the angle of needle would help in entering the system.

Advantages

The authors mention less puncture time with this technique, but it could be a reflection of their experience.

Drawbacks

Inability to judge the plane due to lack of rotation of the fluoroscopy can be a major hindrance for a beginner. Multiple attempts in different angles of the needle are the only option if puncture is not possible.

SUPINE PERCUTANEOUS NEPHROLITHOTOMY

Prone positioning is associated with its share of complications.[35] In the last decade, supine PCNL has gained popularity, especially in morbidly obese patients and in those where a combined antegrade and retrograde approach is needed for stone clearance. Although the initial approaches in supine position were dominantly ultrasonography guided, complete fluoroscopy-guided supine percutaneous renal access is also being practiced.

Patient positioning

In original Valdivia supine position, a 3-litre saline bag is placed under the flank. As simultaneous retrograde manipulation is difficult, a number of modifications have come which include the modified Valdivia position, the Galdakao-modified Valdivia position, complete supine approach, and the Bart's flank-free position. The basic idea is to raise the ipsilateral rib cage and position the legs in lithotomy position so that retrograde manipulation can also be achieved either with semi-rigid or flexible instruments.[36-38]

Determining site of puncture

This is at or below the posterior axillary line as a more anterior approach will be associated with a risk of colonic puncture.[39]

Determining angle of puncture

This is more horizontal and directed toward the target calyx, which could be anterior or a posterior calyx. Most studies have chosen the calyx in the lower and mid pole. Technical difficulties, especially the constraints of space and manipulation of rigid nephroscope have precluded upper pole calyx as the chosen calyx.

Determining depth of puncture

This is done by movements of the C-arm in the different planes. Placing a marker or a hemostat anteriorly on the skin over the target calyx with the C-arm at 0° and then giving the C-arm 30° cranial tilt will give an idea whether the puncture is needle is superficial or deep to the target calyx.[39] This maneuver is similar to the one described with triangulation technique.

Advantages

Feasibility of simultaneous retrograde intrarenal surgery and PCNL is the clear added advantage of supine PCNL over prone PCNL. Less operative time, protection of pressure points, nerves and neck, less cardiovascular, respiratory, and ocular complications are other advantages.[36] The fear that colonic puncture will be more likely in the supine position has not yet been confirmed. Till date, no study has reported this complication in supine PCNL. A more posterior approach and less incidence of retro renal colon in the supine position (0.2%) have been the reasons cited for this.[40,41]

Drawbacks

Restricted operative field, longer tract, increased mobility of kidney during tract dilatation, collapse of pelvicalyceal system during nephroscopy, and inability to make multiple puncture are the shortcomings of supine PCNL. Technically, it is not feasible in patients with calculi in Horseshoe kidney, upper pole, or complete staghorn calculi. Although there are case reports and series on supine PCNL for middle and upper calyceal calculi, technically, it is more demanding and needs ultrasonography-guided puncture for patient safety.[42,43]

COMPARISON OF DIFFERENT TECHNIQUES

Till date, no study has compared the different techniques for percutaneous renal access in prone position. Comparison of bull's eye and the triangulation technique has been done by few studies. Tepeler *et al*.[25] found no difference between the two in terms of fluoroscopy screening time, operation time, hospital stay and need for blood transfusion. They found a slightly higher complication rate and a greater drop in hematocrit in the group undergoing access by the bull's eye technique as compared to the triangulation technique, which was possibly due to the greater torque on the renal parenchyma. However, the difference was not statistically significant. Budak *et al*.[44] had similar findings in their study. A study by Abdallah *et al*. compared the bull's eye with the triangulation technique in a biological model and found no superiority of one over the other[45]Dede *et al*.[46] compared the monoplanar with the biplanar access technique and found that the monoplanar access technique, which is safe to use, decreases puncture time, minimizes the surgeon's direct exposure time to radiation, and has similar success rates as the biplanar access technique. However, this study comes from the group which had published the study on monoplanar access, and hence, the bias of experience and expertise with their own technique could reflect in their results. Literature search showed no study comparing either the bull's eye or the triangulation technique with the hybrid technique. A comparison of the some of the aspects between the different fluoroscopy guided percutaneous renal access techniques in prone position have been described in Table 1.

In comparing the supine with prone PCNL, Zhao *et al*. in their review observed that present evidence shows supine PCNL has the advantages of better cardiovascular and airway control; shorter operation time due to lack of the need for repositioning; and opportunity for a combined retrograde approach. However, the prone position provides a broader surface area for percutaneous access and a wider space for manipulating the nephroscope. Although various modifications of either of the approaches have been described, most reports are based on case series and/or have not obtained their results in a randomized controlled fashion and/or have not been analyzed according to stone complexity and body status, thereby limiting the ability to make strong recommendations.[47]

FUTURE OF PERCUTANEOUS RENAL ACCESS

PCNL is an integral procedure in the armamentarium of any urologist who is dealing with stone disease, and gaining a proper access in the pelvicalyceal system is the corner stone which decides whether the procedure is a success or is associated with complications. Various fluoroscopy techniques have been described for achieving

Table 1: Comparison of different fluoroscopy-guided percutaneous renal access techniques

	Bull's eye	Triangulation	Hybrid	Monoplanar	Supine
Determining site of skin puncture	Describes it	By experience	Describes it	By experience	Along posterior axillary line
Determining angle of puncture	Describes but does not estimate	By experience and movements of C-arm	By using a protractor	By experience and judgment	By experience and movements of C-arm
Determining depth of puncture	By movements of C-arm	By movements of C-arm	Mathematical calculation	By experience	By movements of C-arm
Fluoroscopy time needed for a beginner	Not evaluated	Not evaluated	Not evaluated	Not evaluated	Not evaluated
Attempts needed by a beginner to achieve a successful puncture	Not evaluated	Not evaluated	Not evaluated	Not evaluated	Not evaluated
Accuracy of puncture (exactly) through the fornix	Not evaluated	Not evaluated	Not evaluated	Not evaluated	Not evaluated

a good access. One can use fluoroscopy or ultrasonography or a combination of both for reaching the target calyx. Each of it has its advantages and disadvantages, and no consensus exists showing the superiority of one or the other.[48] Many different strategies have been utilized like use of I pad, electromagnetic tracking device, use of laser-guided Dyna computed tomography, and many others to ease the learning curve and make the procedure more efficacious.[49] Mathematical principles have been used to calculate the access point, direction, and depth of puncture.[32,50,51]

CONCLUSION

For any technique to be well accepted, it should be efficacious and easily reproducible. Among the fluoroscopy-guided access techniques, the bull's eye and the triangulation technique have been used by urologists since many decades. Both are associated with a significant learning curve; hence, newer techniques have been looked for and described. The crux for all these endeavors has been to help the surgeon decide the site of puncture and determine the angle and depth of puncture. Till date only the hybrid technique describes these aspects using mathematical principles. The only way one can determine the superiority of one technique over the other is by a randomized controlled multi-institutional study evaluating the various techniques, and importantly, this should be done by trainees who have no previous experience of using any of the techniques.

Till this is done, endourologists practicing the art of percutaneous access using fluoroscopy should be well versed with the various existing techniques.

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