Original Article

# A mathematical method to estimate angle and distance for percutaneous renal puncture based on computed tomography data: Description and validation

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## Abstract

**Introduction:** Gaining access to the kidney is crucial step in percutaneous nephrolithotomy (PCNL); it has a steep learning curve.

**Objective:** Describe the mathematical method to predict renal puncture angle and distance based on preoperative computed tomography (CT) measurements. Then evaluating how it correlates with measured values.

**Patients and Methods:** The study was prospectively designed. After ethical committee approval, the study uses data from preoperative CT to construct a triangle so we can estimate puncture depth and angle. A triangle of three points, the first is point of entry to the pelvicalyceal system (PCS), the second is point on the skin perpendicular to it, and the third where the needle punctures the skin. The needle travel is estimated using the Pythagorean theorem and puncture angle using the inverse sine function. We evaluated 40 punctures in 36 PCNL procedures. After PCS puncture using fluoroscopy-guided triangulation, we measured the needle travel distance and angle to the horizontal plane. Then compared the results with mathematically estimated values.

**Results:** We targeted posterior lower calyx in 21 (70%) case. The correlation between measured and estimated needle travel distance with Rho coefficient of 0.76 with $P < 0.001$. The mean difference between the estimated and the measured needle travel was – 0.37 ± 1.2 cm (−2.6–1.6). Measured and estimated angle correlate with Rho coefficient of 0.77 and $P < 0.001$. The mean difference between the estimated and the measured angle was 2° ± 8° (−21°–16°).

**Conclusion:** Mathematical estimation of needle depth and angle for gaining access to the kidney correlates well with measured values.

**Keywords:** Fluoroscopy, percutaneous nephrolithotomy, puncture

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## INTRODUCTION

Percutaneous nephrolithotomy (PCNL) is the standard treatment for renal stones larger than 2 cm.[1] PCNL is multistep procedure, each step has its own learning curve, difficulties, and evolution. PCNL main steps are puncture, track establishment, and stone fragmentation and extraction. Puncture remains invariably the first step in any PCNL procedure.[2]

Puncture is the most critical step in PCNL. Failed puncture is reported as a cause abandoning 0%–4% of procedures. The British Association of Urological Surgeons PCNL data registry reported 50 of 5211 (1%) puncture failures that lead to abandoning procedures.[3] Zhu *et al*. reported failed puncture in randomized controlled trial comparing fluoroscopy ($n$ = 146) and ultrasound-guided puncture ($n$ = 147) to be 2.1% and 3.4%, respectively.[4]

Vascular injury requiring angioembolization is a rare but serious complication it may be a consequence of nonpapillary puncture or puncture outside the Brodel's line.[5] Plural injury and hydrothorax increase with supracostal puncture (5%) and the incidence increase to 25% if puncture was performed in the medial half of the rib.[6,7] The preoperative computed tomography (CT) scan can help to identify retrorenal colon, hepatomegaly or splenomegaly, and plan the puncture tract accordingly.[8]

Puncture learning curve is steepest for any PCNL step, as it requires adequate utilization of imaging (ultrasound or fluoroscopy) and proper orientation of renal spatial anatomy.[9] The puncture tract is a line that joins the point of entry from the skin to the targeted calyx; however, its complexity is related to kidney mobility, difference in tissue resistance, and needle bending during puncture.[9,10]

Different techniques and imaging modalities are being used for puncture. Ultrasound and fluoroscopy after passing the learning curve seem to be equally effective. For fluoroscopy-guided puncture biplanar, monoplanar, and triangulation, Bull's eye and hybrid techniques have been described.[11,12]

For a right-angle triangle, if the two legs of the right angle are known the length of the hypotenuse can be estimated using the Pythagorean theorem also the other angles using the inverse sine function.

We made a triangle of three points [Figure 1]. Point C would be the point of access to the pelvicalyceal system (PCS), for example, the posterior lower calyx. Point A would be a perpendicular point on the skin (can be marked by the needle on fluoroscopy or by drawing a line in CT images). Point B would be the point of needle entry at the horizontal plane.

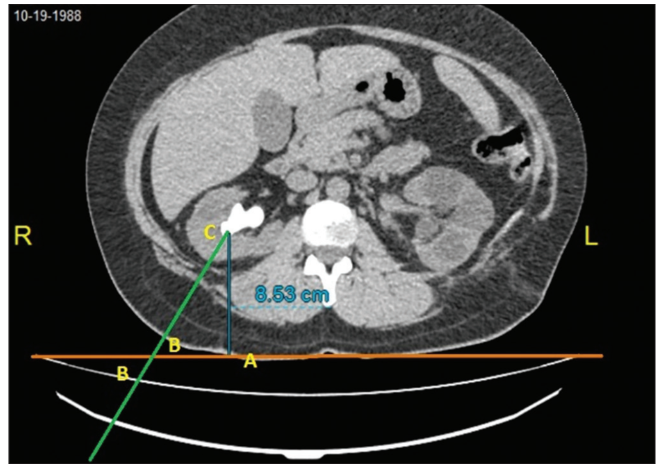



**Figure 1:** A CT image showing the schematic of the triangle based on which the calculation is done. Point C is the point of entry to PCS, point A is the perpendicular point on the skin, Point B is the point of needle entry at the skin. Angle A will always be the right angle. Angle B will be the puncture angle to the horizontal plane. CT: Computed tomography, PCS: Pelvicalyceal system

Angle A would be always perpendicular, the line AC length can be estimated on CT, and line AB length is measured in the theater, after choosing the best tract orientation.

Line BC would be the travel distance and can be estimated using the Pythagorean theorem sum of the squares on the legs of a right triangle is equal to the square on the hypotenuse (BC = $\sqrt{AC^2 + BC}^{2}$).

Angle B would be the angle of the tract to horizontal plane (Puncture angle) and can be estimated using the inverse sine function (B = $arcsine\ \frac{AC}{BC}$)

In theory, we can accurately predict the angle and depth of puncture to access the PCS.

### Aim of the work

The aim of this study is to evaluate the accuracy of mathematically estimated puncture angle and needle travel distance during percutaneous renal access.

## PATIENTS AND METHODS

This study is a prospective observational study. After obtaining ethics review board approval, the patient undergoing PCNL signed informed consent to participate in the study. We evaluated 36 successive patients (total of 40 punctures) undergoing PCNL.

In all cases, puncture was done fluoroscopy guided in prone position using the standard triangulation technique. After confirming access to PCS, the following measures were taken needle travel distance (from horizontal plane to PCS), needle angle to the horizontal plane, and the horizontal distance between the needle entry point on the skin to a point on the skin perpendicular to the PCS access point [Figure 2].

For each patient, a person who was blinded to the measured values, was provided with CT measure of perpendicular distance skin to PCS and distance in horizontal plane between the perpendicular point marked on the skin with needle tip to puncture needle entry point.

Using the Pythagorean theorem, the needle travel distance was estimated and using the inverse sine function to the puncture angle was estimated.

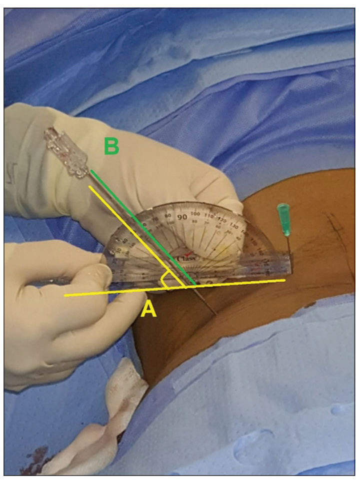



**Figure 2:** Picture showing measurements. Needle tip mark a perpendicular point perpendicular to point of entry to PCS. Angle A is the puncture angle to horizontal plane. B is the distance subtracted from needle length to get needle travel distance. PCS: Pelvicalyceal system

Data were collected tabulated and analyzed using Stata 12.0 software (Stata Corporation, College Station, TX, USA). For correlation, we used Spearman's correlation test. We used $P < 0.05$ as statistically significant results.

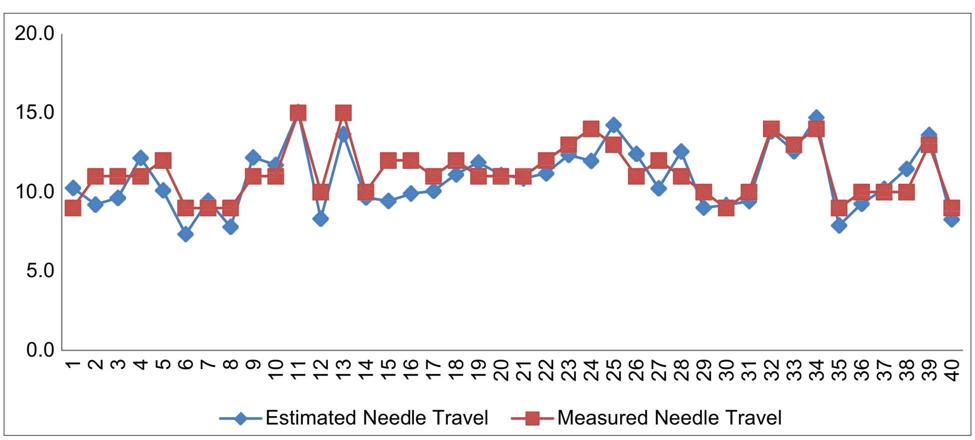
## RESULTS

The study included 36 consecutive patients (40 punctures) undergoing PCNL between March 2021 and March 2022. The mean age of patients was 49.5 ± 11.3 years. Punctures were on the right side 23 (57%) times and on left side in 17 (43%) times. Subcostal puncture was utilized 24 (60%) times and supracostal 16 (40%) times.

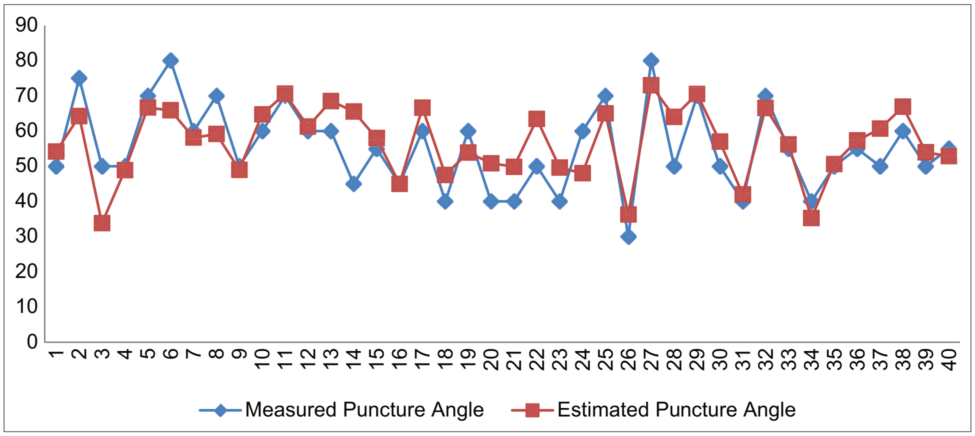
The posterior lower calyx was the most commonly targeted calyx in 28 (70%) punctures, followed by middle posterior in 7 (17%), upper calyx in 3 (7.5%), and anterior lower calyx in 2 (5%).

When comparing the measured versus estimated needle travel distances, the measured travel distance range was 9–15 cm and the mean was 11 ± 1.7 cm, whereas estimated travel distance range was 7.3–15.1 cm and the mean was 10.6 ± 2 cm. They both correlated well with Spearman's Rho of 0.77 and $P = 0.001$. The difference between the measure and estimated travel distance mean was –0.37 ± 1.2 cm and the range was −2.6–1.6 cm [Graph 1].

Comparing estimated and measured puncture angles, the measured angle range was 30°–80° and the mean was 55° ± 12°, whereas estimated puncture angles were 33°–73° and the mean was 57° ± 10°. They both correlated well with spearman's Rho of 0.76 and $P = 0.001$. The difference between the measure and estimated puncture angle mean was 2° ± 8° and the range was −21°–16° [Graph 2].




**Graph 1:** Measured versus estimated needle travel distance in centimeters




**Graph 2:** Measured versus estimated puncture angle

## DISCUSSION

Puncture is the key step for successful PCNL procedure and it is the hardest to master.[9] Assessing the puncture learning curve is difficult as several parameters can be used number of puncture trials, fluoroscopy time, or time. None of them is a standard benchmark for puncture proficiency. Allen *et al*. reported a progressive decrease in fluoroscopy time as experience grows and noted that till 115 cases.[13]

Improving puncture quality is a progressing endeavor several models both biological and automated were used to improve training.[14]

Sharma and Sharma used Bull's eye technique to estimate the angle of puncture then applying trigonometric equation they estimated the depth of the puncture with great accuracy. They estimated the difference to be 0–3 mm and achieved puncture in the first trial in 95% of cases.[15]

In this study, we used data from CT and selected point of entry to estimate both depth and angle of the puncture.

We found a good correlation between estimated and measured values for puncture angle and needle travel distance with a $P < 0.001$ and Rho coefficient of 0.76 and 0.77 consecutively. Despite the mathematical model did not perfectly estimate the length nor the angle, the range of error was −2.6–1.6 cm for distance and −21°–16° for angle.

We believe that there are changes that happen during puncture compared to static pictures captured during CT. First, all patient CTs were in supine position, and puncture was done in prone position. Kidney movement during respiration and movement of the kidney with the needle pressure till it have enough force to get into the PCS. Furthermore, needle bend due to different degrees of resistance in the tissue is a documented phenomenon.[10]

This model would give a reliable prediction with minimal need for adjustment; we anticipate that this would be particularly valuable for residents and surgeons in their early PCNL careers. We went ahead and developed a web-based calculator to make it accessible for as many surgeons as possible (https://app.calculoid.com/?#/calculator/91469).

## CONCLUSION

Mathematical estimation of percutaneous pelvicalyceal puncture using data acquired from CT correlates well with both measured needle travel distance and angle with reasonable margin of error.

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Nil.

### Conflicts of interest

There are no conflicts of interest.

## REFERENCES

1. EAU Guidelines (Urolithiasis). Available from: https://uroweb.org/guideline/urolithiasis. [Last accessed on 2022 Feb 06].
2. Knoll T, Daels F, Desai J, Hoznek A, Knudsen B, Montanari E, *et al*. Percutaneous nephrolithotomy: Technique. World J Urol 2017;35:1361-8.
3. Armitage JN, Withington J, Fowler S, Finch WJ, Burgess NA, Irving SO, *et al*. Percutaneous nephrolithotomy access by urologist or interventional radiologist: Practice and outcomes in the UK. BJU Int 2017;119:913-8.

4. Zhu W, Li J, Yuan J, Liu Y, Wan SP, Liu G, *et al*. A prospective and randomised trial comparing fluoroscopic, total ultrasonographic, and combined guidance for renal access in mini-percutaneous nephrolithotomy. BJU Int 2017;119:612-8.
5. Kim HY, Lee KW, Lee DS. Critical causes in severe bleeding requiring angioembolization after percutaneous nephrolithotomy. BMC Urol 2020;20:22.
6. Ozgor F, Tepeler A, Basibuyuk I, Kucuktopcu O, Kayali Y, Yanaral F, *et al*. Supracostal access for miniaturized percutaneous nephrolithotomy: Comparison of supracostal and infracostal approaches. Urolithiasis 2018;46:279-83.
7. He Z, Tang F, Lu Z, He Y, Wei G, Zhong F, *et al*. Comparison of supracostal and infracostal access for percutaneous nephrolithotomy: A systematic review and meta-analysis. Urol J 2019;16:107-14.
8. Marchini GS, Berto FC, Vicentini FC, Shan CJ, Srougi M, Mazzucchi E. Preoperative planning with noncontrast computed tomography in the prone and supine position for percutaneous nephrolithotomy: A practical overview. J Endourol 2015;29:6-12.
9. Alken P. Percutaneous nephrolithotomy – The puncture. BJU Int 2022;129:17-24.
10. Liu W, Yang Z, Fang P, Jiang S. Deflection simulation for a needle adjusted by the insertion orientation angle and axial rotation during insertion in the muscle-contained double-layered tissue. Med Biol Eng Comput 2020;58:2291-304.
11. Sharma GR, Luitel B. Techniques for fluoroscopy-guided percutaneous renal access: An analytical review. Indian J Urol 2019;35:259-66.
12. Yang YH, Wen YC, Chen KC, Chen C. Ultrasound-guided versus fluoroscopy-guided percutaneous nephrolithotomy: A systematic review and meta-analysis. World J Urol 2019;37:777-88.
13. Allen D, O'Brien T, Tiptaft R, Glass J. Defining the learning curve for percutaneous nephrolithotomy. J Endourol 2005;19:279-82.
14. Farcas M, Reynolds LF, Lee JY. Simulation-based percutaneous renal access training: Evaluating a novel 3D immersive virtual reality platform. J Endourol 2021;35:695-9.
15. Sharma G, Sharma A. Determining the angle and depth of puncture for fluoroscopy-guided percutaneous renal access in the prone position. Indian J Urol 2015;31:38-41.