The efficacy and safety benefit of the preoperative three-dimensional surgical simulation for percutaneous nephrolithotomy through the renal tract

メタデータ	言語: English 出版者: 公開日: 2023-03-06 キーワード (Ja): キーワード (En): 作成者: 野間, 康央 メールアドレス: 所属:
URL	https://jair.repo.nii.ac.jp/records/2003067

Journal of Urology and Renal Diseases
Noma Y, et al. J Urol Ren Dis 07: 1297.
www.doi.org/10.29011/2575-7903.001297
www.gavinpublishers.com

OPEN ACCESS

GAVIN PUBLISHERS

Research Article

The Efficacy and Safety Benefit of the Preoperative Three-Dimensional Surgical Simulation for Percutaneous Nephrolithotomy Through the Renal Tract

Yasuhiro Noma[1*], Shuji Isotani[1], Takeshi Ashizawa[1], Hisashi Hirano[1], Toshiyuki China[1], Haruna Kawano[1], Fumitaka Shimizu[1], Masayoshi Nagata[1], Yuki Nakagawa[1], Satoru Muto[2], Shigeo Horie[1]

Department of Urology, Juntendo University Hospital, Tokyo, Japan

Department of Urology, Juntendo University Nerima Hospital, Tokyo, Japan

***Corresponding author:** Shuji Isotani, Department of Urology, Juntendo University Hospital, 3-1-3 Hongo3cho-me, Bunkyo-ku, Tokyo 113-0033, Japan

Citation: Noma Y, Isotani S, Ashizawa T, Hirano H, Shimizu F, et al. (2022) The Efficacy and Safety Benefit of the Preoperative Three-Dimensional Surgical Simulation for Percutaneous Nephrolithotomy Through the Renal Tract. J Urol Ren Dis 07: 1297. DOI: 10.29011/2575-7903.001297.

Received Date: 22 November, 2022**; Accepted Date:** 28 November, 2022**; Published Date:** 01 December 2022

Abstract

Objectives: We examined the usefulness of pre-operative 3D surgical simulation in Percutaneous Nephrolithotomy (PCNL).

Methods: We retrospectively assessed the 26 cases that underwent 3D surgical simulation for PCNL conducted at Juntendo University from September 2015 to April 2020 with comparing to 22 cases that did not undergo surgical simulation. In the 3D surgical simulation group, we underwent detailed CT examinations before surgery, followed by 3D simulation used image analysis software for segmentation, identified all anatomical structures related to the surgery to identify the point of the simulated renal tracts that were thought to be safe and efficient for stone free. At the surgery, the entry point of the renal tract on the patient body surface was identified with referring the 3D surgical simulated image.

Results: There were no differences in patient background characteristics in gender, BMI, stone size, and Guy's score between the 3D surgical simulation and non- 3D surgical simulation group. The stone-free rate (SFR) was 76.9% (20/26 cases) in the created group and 45.4% (10/22 cases) in the non-created group, and the SFR was superior in the 3D surgical simulation group ($p = 0.02$). Furthermore, perioperative complications were fewer in the created group (created group, 1 case; non-created group, 4 cases [$p = 0.09$]).

Conclusions: Based on these results, we believe that the accomplishment of pre-operative 3D surgical simulation for PCNL could increase the efficiency of stone removal and minimize the risk of renal puncture.

Keywords: 3D model construction; Kidney stone; PCNL

Introduction

Percutaneous Nephrolithotomy (PCNL) was first performed in 1976 [1], and it is currently the recommended first-line of treatment for large kidney stones, including staghorn stones [2-4]. The surgical treatment of PCNL has a high stone-free rate relative to other surgeries, however, some serious complications such as fever, major bleeding, or organ injuries were reported at the operation. Predictors of bleeding during PCNL were demonstrated as stag-horn stones, multiple punctures, puncture of the superior calyx, and operator experience [5]. Severe bleeding occurs from damage to the interlobar arteries or veins that surround the calyx by the puncture or renal laceration with the renal tract. Therefore, the ideal tract should be placed straight from the center of the renal calyx to the uretero renal junction in the renal pelvis via targeted renal stone [6]. Moreover, for achieving a safe operation, it is required to avoid organ injuries, such as the thoracic cavity, colon, spleen, or liver. However, creating a renal access tract in the ideal position without visualizing the anatomy requires performing a high skill set with identifying the position of intrarenal tissue, such as the renal pelvis, under ultrasound guidance, and it makes difficulties of this surgical procedure [7,8]. Therefore, we constructed a Three-Dimensional (3D) model of kidney stones using contrast-enhanced CT, used pre-operative 3D surgical simulation to plan the location of the renal tract, and then performed the actual surgery. We then compared the group of patients for which this was performed with a control group for which no image reconstruction was done, and we retrospectively investigated the effectiveness of the procedure.

Patients and Methods

The 48 patients who underwent PCNL at Juntendo University from September 2015 to April 2020 (partial/complete staghorn stones, 20 cases; multiple kidney stones, 25 cases; ureteral stones, 3 cases) were included in this study. We retrospectively assessed the eligibility for 26 cases for which pre-operative 3D surgical simulations were performed (3D simulation group) by comparing the 22 cases without simulations (non-simulation group). As a timeline, the 3D simulation group was performed after the surgeries of the non-creation group. Every surgery was performed by two experienced surgeons and assistants with varying skill levels.

3D Surgical Simulation

In our hospital, PCNL was performed in the prone position. For the patient in the 3D simulation group, we conducted contrast-enhanced CT examinations in the prone position similar to the position used for surgery throughout the CT scanning process. A 64-row multi-slice CT scanner (Philips, Brilliance 64, Netherlands) was used to perform CT scans in four phases (simple, arterial, venous, excretory) in 0.5-mm slices. The contrast medium was intravenously injected, with the arterial phase set at 25 seconds, the venous phase set at 60 seconds, and the excretory phase set at 3-5 minutes after injection of contrast. 3D reconstruction of the images for all cases was performed by the two experienced urologists by using imaging software (Volume Analyzer SYNAPSE VINCENT; FUJIFILM Corporation, Tokyo, Japan) was used for surgical simulation. At first, the renal parenchyma renal artery, renal vein, renal stone, ureter, spine, rib, lung, liver, spleen, and skin were subsequently extracted from the CT images of each patient and combined with adjusting the transparency of each reconstructed organ (Figures 1a-d). Then pre-operatively planned puncture (3D surgical simulation), was determined using the imaging software by the surgeon. The virtual renal tract was assumed in the constructed 3D renal image, with rotating the image and determining the puncture tract line from multiple directions. The safest and most efficient virtual tract among these (i.e., the position that does not damage the blood vessels in the kidney and adjacent organs) and which creates a straight line between the target stones and the ureteropelvic junction was created in the virtual space. The depth of the puncture (i.e., depth of the puncture needle from the skin to renal pelvis), the horizontal distance between the puncture site and midline of the spine, and vertical distance to the 12th rib were recorded (Figure 2a,b).

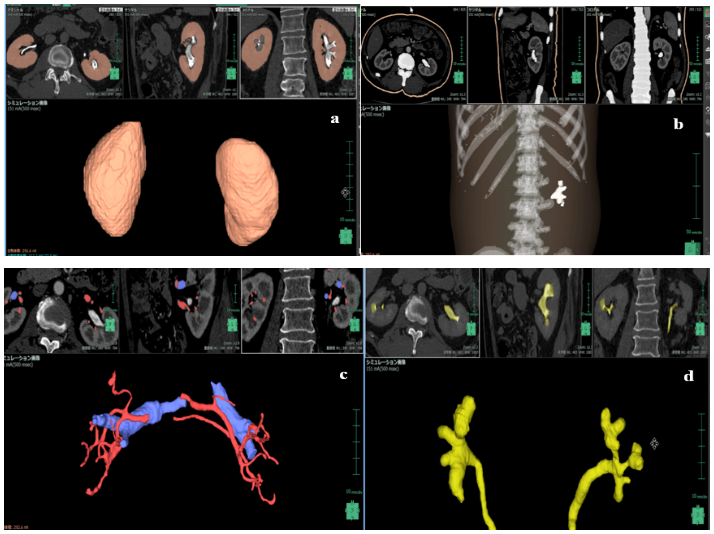

Figure 1(a-d): Anatomical segmentation from preoperative CT image. **(a)** Extraction of renal parenchyma; **(b)** Extraction of kidney stones; **(c)** Extraction of renal blood vessels (renal artery, renal vein); **(d)** Extraction of urinary tract.

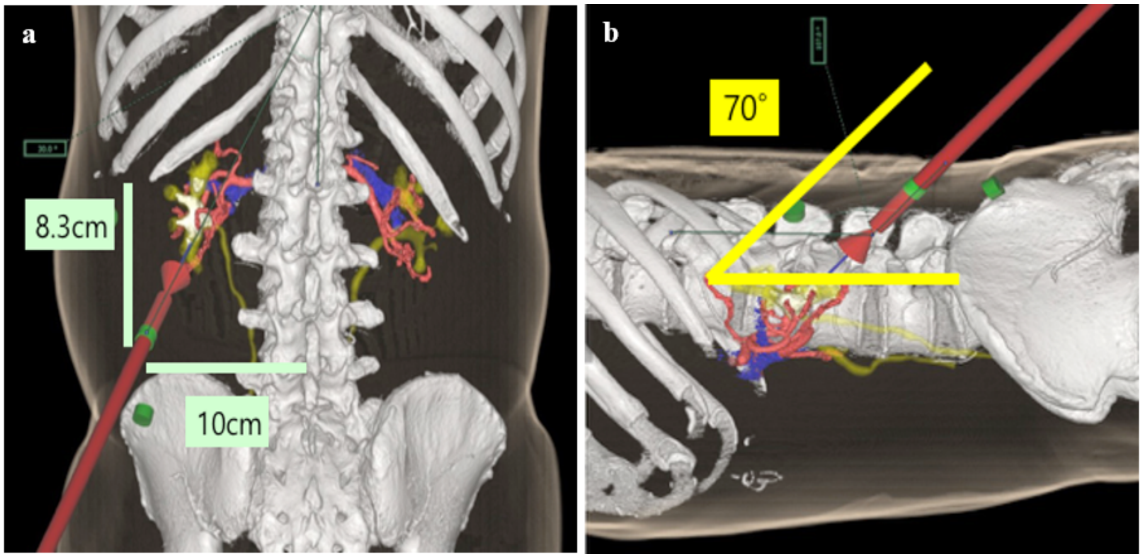

Figure 2 (a, b): 3D surgical simulation. **(a)** Imaging of renal tract (the puncture line) in the coronal plane from the back; **(b)** Imaging of renal tract (the puncture line) in the sagittal image from the right side.

PCNL Procedure

The surgery was performed in the prone position as with the CT conducted prior to surgery. The 3D model of the kidney stones was displayed on the imaging screen at the front of the surgeon. The simulated tract puncture line was marked on the patient's back with comparing 3D model (horizontal distance between the puncture site and midline of the spine, and vertical distance between the puncture site and 12th rib). The tract puncture was performed using the 21G puncture needle to make the tract according to the predetermined puncture tract under ultrasound guidance. To minimize spatial error when puncturing, anesthesiologists maintained the same respiratory conditions (i.e., inspiration) as same respirating condition as CT imaging examination. In the absence of hydronephrosis, a UPJ occlusion balloon catheter was used to create hydronephrosis before puncture. Tract dilation was performed using the Bard X-force balloon dilator to 30F dilation. An Amplatz sheath was introduced over the balloon dilator under fluoroscopic guidance. For everycases in this study, the 24Fr rigid nephroscope (Olympus, Tokyo, Japan) was introduced, and lithotripsy was performed using pneumatic and ultrasonic lithotripters Swiss LithoClast (Swiss LithoClast Master; EMS, Nyon, Switzer- land). We also rotated the 3D model on the screen at various angles during the surgery, and the surgery was conducted while comparing it with the actual surgical image and transparent image. For each case, the age, BMI, Guy's score, stone removal viability, Hounsfield Units (HU) value of stones on CT, operation time, hemoglobin decreases after surgery, and perioperative complications were recorded. The HU value was determined by measuring three points on the stone and taking its average value. Post-operative evaluations involved conducting CT 2-4 weeks after the D-J stent was removed and evaluating the residual stones. The Stone free rate (SFR) was defined as the absence of residual stones with a size of 3 mm or greater [9,10].

Results

The 3D surgical simulations were performed for 26 patients (3D surgical simulation). The constructed 3D models enabled the clear visualization of the renal arteries, renal veins, renal pelvis, and ureter by adjusting the transparency of the kidney. Furthermore, the number and shape of the kidney stones, as well as the dilation of the renal pelvis, could be determined; and the positional relationship of adjacent organs such as the kidney, spine, ribs, lungs, liver, and spleen were presented on the screen. Comparisons and investigations were conducted for 22 patients who underwent PCNL without image reconstruction (non-3D surgical simulation group.) (Table 1). The 3D surgical simulation group had an average maximum diameter of the stones of 31.9 mm (non-3D surgical simulation group 36.6 mm; $p = 0.25$), stone volume of 11.1 cm^3 (non-3D surgical simulation group, 11.3 cm^3; $p = 0.89$), average Guy's score of 2.7 (non-3D surgical simulation group, 2.7; $p = 0.66$), and post-operative hemoglobin decrease of 0.6 g/L non-3D surgical simulation group, 1.0 g/L; $p = 0.20$). Furthermore, the created group had a first-session stone-free rate (SFR) of 76.9% (non-3D surgical simulation group, 45.4%; $p=0.025$) (Table 2), and all stones were removed in cases in the 3D surgical simulation group where residual stones were observed on second surgery. With regards to perioperative complications, there was only one patient who had a post-operative fever in the 3D surgical simulation group (Clavien-Dindo classification, Grade 1), compared with, 4 cases in non-3D surgical simulation, including 3 fever cases (Grade 1, 2 cases; Grade 2, 1 case) and 1 bleeding case (Grade 2); p=0.1.

	Sex	Age	Stone side	BMI	length of the patients stay in the hospital,	Number of complications
Created group (26 cases)	20 men, 6 women	60.9	Right 14 Left 12	24.3	12.3	1
Non-created group (22 cases)	15 men, 7 women	57.2	Right 8 Left 14	23.1	12.5	4
p value	0.49	0.26	0.22	0.31	0.68	0.10

	SFR (first-session stone-free rate)	the final stone clearance rate	Guy's score	Maximum stone diameter	Stone volume	Average HU value	Change in Hb
Created group (26 cases)	76.90%	100.0%	2.7	31.9mm	11.1cm³	521.4	0.6
Non-created group (22 cases)	45.40%	90.9%	2.7	36.6mm	11.3cm³	533.7	1
p value	0.025	0.11	0.66	0.25	0.89	0.84	0.20

Discussion

According to Japanese urolithiasis clinical guidelines, PCNL is indicated for staghorn l stones or renal stones measuring 20 mm or more [4]. Particularly the staghorn stones may recur if residual stones are present after surgery; therefore, a complete stone-free state must be essential for PCNL procedure. There are many reported advantages of favorable operative results by PCNL because with PCNL the distance from the body surface is relatively short, the access tract is wide, and this procedure allows for the removal and collection of stones within a short period because even large crushed stone pieces can be easily extracted. At the operation, creating the tract is important to avoid the complications such as cortical infarction, renal bleeding, laceration, and damage to other organs. It can occur due to damage to the small arteries and inadequate angle of the renal tract. The poor puncture position also leads to the application of a high amount of pressure during the stone-crushing procedure, which reads to the renal cortex laceration. In other words, safely and optimally constructing the tract is one of the most important processes in this surgery.

The surgical positions of PCNL include several types of the operative position including prone positions, lateral decubitus position, supine position, and modified Valdivia position. There is still ongoing debate about which surgical position is the most appropriate. Many reports suggested a higher stone-free rate in the prone position than in the supine position, so, in our hospital, we conducted PCNL with the prone position [11,12]. The procedure for creating the tract at our hospital was performed under fluoroscopic and ultrasound guidance. Both ultrasound and fluoroscopic images are performed under two-dimensional imaging. At the operation, it is difficult to know where the appropriate tract position since the anatomical position of structures cannot be seen through the human body. Our reconstruction 3D surgical simulation model for PCNL in this study enabled us to indicate the ideal tract position that is a direct line between the stones and ureteropelvic junction with avoiding the organ injury by visualization of the renal arteries and veins around the puncture allows for the pre-operative imaging of the area occupied by blood vessels [13,14]. The SFR in the created group was significantly higher than that in the non-created group, and the perioperative complications and post-operative Hb decrease tended to be lower in the created group. It suggested that the 3D surgical simulation might have contributed to the safety of the PCNL procedure [15].

There are some new technologies reported in recent years for creating renal tract with PCNL procedure. Lima et al reported that the method which performed with both combination ultrasound images and CT images in real-time using electromagnetic waves [16]; Rassweiler et al also reported another procedure which the renal tract puncturing is performed by assuming the position of the kidney after incorporating the CT images constructed in 3D in advance into an iPad and combining the camera image and CT image [17]. In 2017, Hamamoto et al proposed that electromagnetic waves are projected to the puncture site from a ureteroscope placed in the renal pelvis, and the puncturing is performed in the direction of the waves [18], and Ritter M conducted that making renal tract while confirming the positions of the stones and anatomical structures in real-time using DynaCT in 2015 [19].

However, all of these are surgical procedures were requiring some new devices, and none of them focus the allowing for a pre-operative 3D simulation which indicated the most appropriate puncture line for the surgery. Our procedure is able to reproduce only with pre-operative contrast-enhanced CT and imaging software for reconstructing 3D images, furthermore, similar 3D reconstruction has already been done in urinary surgery [20,21], which suggests that image reconstruction is not too complicated. However, there is some limitation with this study. The first limitation is the radiation exposure dose in the patient as a result of performing a four-phase contrast-enhanced CT as opposed to the conventional un-enhanced CT. The second is that the image 3D reconstruction from Ct scanning was performed manually by the surgeon, so this may need time around 60 minutes for each 3D surgical simulation. A prospective study is required to determine the significance of creating a 3D model, considering the planning time and surgical response. Furthermore, even the renal tract punctures were performed under the 3D simulation at the expected sites in this study, we did not confirm it as a real-time image; therefore. there might have been including some degree of image difference possible, and the puncture technique of the operator may affect the puncture.

However, even with these limitations, our study suggests that pre-operative 3D surgical simulation is able to improve the efficacy and safety of PCNL through the process of creating better renal tracts. The new imaging technology may have a therapeutic effect on the treatment and more cases will be needed to show the effect of this method, we encourage other centers and surgeons to publish their clinical results. And although the surgery was performed by a surgeon with sufficient experience, the possibility of a learning curve remains because this time the created group was performed after the non-created group.

3D surgical simulation prior to PCNL minimized the risks associated with percutaneous treatment, and we suggest that this may be a tool for surgical support to achieve a higher SFR in a single surgery. Our findings suggest that the concept of preoperative imaging assistant can be an operating tool to improve the efficiency and safety of the procedure.

References

1. Fernström I, Johansson B (1976) Percutaneous pyelolithotomy. A new extraction technique. Scand J Urol Nephrol 10: 257-259.
2. Türk C, Petřík A, Sarica K (2016) EAU guidelines on interventional treatment for urolithiasis. Eur Urol 69: 475-482.
3. Assimos D, Krambeck A, Miller NL (2016) Surgical management of stones: American Urological Association/Endourological Society guideline, part I. J Urol 196: 1153-1160.
4. Japanese Urological Association, ed., Japanese urolithiasis clinical guideline (2013 edition), Kanehara Shuppan.
5. El-Nahas AR, Shokeir AA, El-Assmy AM (2007) post-percutaneous nephrolithotomy extensive hemorrhage: a study of risk factors. J Urol 177: 576-579.
6. Sampaio FJ, Zanier JF, Aragão AH, Favorito LA (1992) Intrarenal access: 3-dimensional anatomical study. J Urol 148: 1769-1773.
7. Watterson JD, Soon S, Jana K (2006) Access related complications during percutaneous nephrolithotomy: urology versus radiology at a single academic institution. J Urol 176: 142-145.
8. Mishra S, Sabnis RB, Desai M (2012) Staghorn morphometry: a new tool for clinical classification and prediction model for percutaneous nephrolithotomy monotherapy. J Endourol 26: 6-14.
9. Tanriverdi O, Boylu U, Kendirci M, Kadihasanoglu M, Horasanli K, et al. (2007) The learning curve in the training of percutaneous nephrolithotomy. Eur Urol 52: 206-211.
10. Jang WS, Choi KH, Yang SC, Han WK (2011) The learning curve for flank percutaneous nephrolithotomy for kidney calculi: a single surgeon's experience. Korean J Urol 52: 284-288.
11. Yuan D, Liu Y, Rao H (2016) Supine versus prone position in percutaneous nephrolithotomy for kidney calculi: a meta-analysis. J Endourol 30: 754-763.
12. Astroza G, Lipkin M, Neisius A (2013) Effect of supine vs prone position on outcomes of percutaneous nephrolithotomy in staghorn calculi: results from the clinical research office of the endourology society study. Urology 82: 1240-1244.
13. Rastinehad AR, Andonian S, Smith AD, Siegel DN (2009) Management of hemorrhagic complications associated with percutaneous nephrolithotomy. J Endourol 23: 1763-1767.
14. Richstone L, Reggio E, Ost MC (2008) First Prize (tie): hemorrhage following percutaneous renal surgery: characterization of angiographic findings. J Endourol 22: 1129-1135.
15. Li H, Chen Y, Liu C, Li B, Xu K, et al. (2013) Construction of a three dimensional model of renal stones: comprehensive planning for percutaneous nephrolithotomy and assistance in surgery. World J Urol 31: 1587-1592.
16. Lima E, Rodrigues PL, Mota P (2017) Ureteroscopy-assisted percutaneous kidney access made easy: first clinical experience with a novel navigation system using electromagnetic guidance (IDEAL Stage1). Eur Urol 72: 610-616.
17. Rassweiler J, Rassweiler MC, Klein J (2016) New technology in ureteroscopy and percutaneous nephrolithotomy. Curr Opin Urol 26: 95-106.
18. Hamamoto S, Unno R, Taguchi K (2015) A new navigation system of renal puncture for endoscopic combined intrarenal surgery: real-time virtual sonography-guided renal access. Urology 109: 44-50.
19. Ritter M, Rassweiler MC, Michel MS (2015) The Uro Dyna-CT enables three-dimensional planned laser-guided complex punctures. Eur Urol 68: 880-884.
20. Teber D, Guven S, Simpfendörfer T (2009) Augmented reality: a new tool to improve surgical accuracy during laparoscopic partial nephrectomy? Preliminary in vitro and in vivo results. Eur Urol 56: 332-338.
21. Rassweiler JJ, Müller M, Fangerau M (2012) iPad-assisted percutaneous access to the kidney using marker-based navigation: initial clinical experience. Eur Urol 61: 628-631.