Original Article

The effect of percutaneous tract dilation technique on renal parenchymal trauma: An experimental *in vivo* study on a porcine model

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Abstract

Purpose: The purpose of this study was to evaluate renal parenchymal trauma of two-step dilation compared to the conventional Amplatz gradual dilation during percutaneous nephrolithotomy on a porcine model.

Materials and Methods: A nonpapillary percutaneous access tract was established under fluoroscopic guidance in both kidneys of four female pigs. On the right kidney of each pig, gradual dilation was performed using an Amplatz dilator set with a gradual dilation to 30 Fr, whereas on the left, a two-step dilation was utilized using only 16 Fr and 30 Fr dilators. Two of the animals were euthanized immediately after the procedure and the remaining two 1 month later. The pigs that were kept alive underwent a contrast-enhanced computed tomography immediately, 15, and 30 days postoperatively. A dimercaptosuccinic acid (DMSA) scintigraphy and single-photon emission computed tomography–computed tomography (CT) were also performed after the last CT and afterward, the pigs were sacrificed. All kidneys were harvested for pathohistological examination.

Results: The follow-up radiologic imaging showed similar parenchymal damage caused by the compared dilation techniques and an expected reduction in scar size in the later scans. No scar was identified by DMSA in any kidney. Gross and microscopic examinations conducted both on the kidneys that were harvested immediately after the procedure and the ones from the animals that were left to heal, revealed no significant differences in tissue damage, grade of fibrosis, or inflammation depending on the dilation method.

Conclusions: Our study showed no inferior outcomes caused by two-step dilation compared to gradual dilation regarding renal parenchymal damage following a nonpapillary puncture. In fact, postoperative imaging findings suggested a trend toward better healing and less scar tissue when the two-step method was used.

Keywords: Dilation, percutaneous nephrolithotomy, renal parenchymal trauma

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INTRODUCTION

Percutaneous nephrolithotomy (PCNL) is accepted as the gold standard for the treatment of renal stones larger than 2 cm.[1] The puncture and subsequent dilation to create the access tract are the initial and essential steps for the success of the procedure.

The standard methods for dilation include Amplatz fascial dilators, Alken dilators, balloon dilators, and a "one-shot" method.[2] The "one-shot" dilation technique, which consists of a single dilation with a 25–30 Fr Amplatz dilator instead of gradual dilation, was reported to have similar results in terms of morbidity and blood loss while being associated with improved operative time.[3] The four methods of tract dilation were compared in a prospective randomized study. The techniques were found to be equally safe and effective, while "one-shot" and balloon dilation were the least time-consuming and required less fluoroscopy time.[2] In addition, the "one-shot" method was suggested as the method of choice, especially in developing countries, given it is the cheaper option.[2]

In our clinical practice, a two-step technique using 16 Fr and 30 Fr Amplatz dilators has been used for creating a working PCNL tract for a long period of time[1] without encountering any significant complications. In addition, our technique of nonpapillary puncture PCNL was reported to have a similar rate of complications while limiting the operative time and the radiation exposure for the patients and the surgeons.[1,4]

These puncture and dilation techniques have been shown to be safe and effective in our hands, however, there is limited evidence objectively evaluating the damage caused by the dilation technique in the literature. Therefore, the aim of this study was to assess and compare the tissue damage of nonpapillary tract dilation to 30 Fr using gradual and two-step dilation techniques.

MATERIALS AND METHODS

Study design

An *in vivo* experimental study was conducted to compare the tissue damage of two-step dilation and gradual dilation techniques after percutaneous nonpapillary access on porcine models. The study received ethical approval from the responsible Veterinary Service of the State. Four female pigs weighing more than 30 kg, for a total of 8 renal units were required for this study. On one kidney of each pig, dilation was achieved using gradual dilation, and on the other, the two-step method was used. Therefore, the effect of each method on renal tissue was evaluated in four kidneys. Both the immediate and the delayed impact of the dilation on the renal tissue were investigated. Two pigs were sacrificed immediately after the experiment. The remaining were left alive to allow the surgery site to heal and were sacrificed 4 weeks later [Table 1].

Preparation and postprocedural care of the pigs

In preparation for the operation, the pigs were nil per Os for 12 h. To start the anesthesia, ketamine, xylazine, and midazolam were administered, before an intubation tube, connected to the ventilation machine, was introduced. Maintenance of anesthesia was achieved with intravenous administration of propofol through a peripheral intravenous cannula. Paracetamol was used for analgesia.

Technique and evaluation of the renal tissue damage

The pigs were anesthetized and placed in the supine position. After locating the ureteric orifices using cystoscopy, a ureteral catheter was advanced up to the pelvis of the kidneys under radiologic monitoring. Afterward, the animals were placed in the prone position. A nonpapillary percutaneous puncture was performed, following a conventional fluoroscopic guided biplanar puncture protocol. On one kidney of each pig, tract dilation was achieved through gradual dilation using an Amplatz dilator set from 8 Fr to 30 Fr (Cook Medical, Cook Ireland Ltd., Limerick, Ireland), while on the other, two-step dilation was performed using only 16 Fr and 30 Fr dilators. For tracking purposes, conventional gradual dilation was performed on the right side of the pigs, whereas the left side was reserved for the two-step method. The access sheaths were left in place for 45 min to simulate the time span of a regular PCNL case. Afterward, the sheaths were removed, and the skin defects were closed without leaving any tubes. According to the protocol described earlier, the animals were euthanized immediately after the experiment or 4 weeks later. A contrast-enhanced computed tomography was performed on the animals that were kept alive immediately after the experiment, 2 weeks, and 4 weeks later. A dimercaptosuccinic acid (DMSA) scintigraphy and single-photon emission computed tomography–computed tomography (SPECT-CT) were also performed 2 days after the last CT and afterward, the pigs were sacrificed [Table 1]. The kidneys of the pigs were harvested and sent for histological evaluation of the tissue damage. The examination was conducted by a pathologist using hematoxylin–eosin and mason staining to assess the grade of inflammation and fibrosis and the maximal diameter of the scar tissue.

RESULTS

Pathology

A histological examination was conducted on all eight kidneys. Macroscopic images of the kidneys are presented in Figure 1. Specimens number 3 and 4 were sacrificed immediately after the experiment while Model number1 and 2 were after 1 month.

On Specimen number 3, a 14-mm tear and a 15-mm round defect were present on the posterior side of the left (two-step dilation) and right kidney (gradual dilation), respectively [Figure 1a and b]. Signs of intense bleeding with no apparent inflammation or fibrosis were reported from the microscopic examination. Both kidneys carried a cylindrical defect with a 5–6-mm diameter at their wider point [Table 2].

Regarding Specimen number 4, a 15-mm tear was identified on the posterior surface of the left kidney [Figure 1c], whereas on the posterior side of the right one, a 14-mm round defect was present [Figure 1d]. Microscopic evaluation revealed no evidence of inflammation or fibrosis on either kidney, but a 5-mm defect was reported on the left one and a 4-mm defect on the right one [Table 2].

Even though one puncture was required to create the access tract, traumatic bleeding areas around the puncture site were found on all four kidneys.

On Specimen number 1, both kidneys carried linear scars of about 3 mm in size. It is noteworthy that the scars on both kidneys had a connective tissue formation attached on them. Following the incision, a 2-mm diameter linear scar was identified on both the right and left kidneys. Microscopic examination of the right kidney identified evidence of moderate fibrosis, pronounced inflammation, granulation tissue, angiogenesis, and hemosiderin and a horseshoe-shaped scar. Fibrotic tissue of 1 mm was present on the superior side of the scar and granuloma tissue of 3 mm on the inferior side. The left kidney carried a 1-mm diameter scar with signs of moderate fibrosis and inflammation, as well as granuloma, angiogenesis, and hemosiderin [Table 2].

On Specimen number 2, there was a 3-mm scar on the left kidney and a 5-mm scar of triangular shape on the right kidney. The incision of the left kidney revealed a cone-shaped scar with a 1-mm diameter at its peak facing

Table 1: *In vivo* experimental set-up

In vivo trials	Time of nephrectomy	Gradual dilation (right kidney) (Fr)	Two-step dilation (left kidney) (Fr)	Imaging studies performed
Model 1	30 days after the dilation	30	30	Contrast-enhanced CT scan, DMSA SPECT-CT
Model 2	30 days after the dilation	30	30	Contrast-enhanced CT scan, DMSA SPECT-CT
Model 3	45 min after the dilation	30	30	-
Model 4	45 min after the dilation	30	30	-

CT: Computed tomography, SPECT-CT: Single-photon emission CT, DMSA: Dimercaptosuccinic acid

Table 2: Pathology report

Animal	Inflammation		Fibrosis		Scar maximal diameter		CT maximal diameter	
	Right	Left	Right	Left	Right (mm)	Left (mm)	Right (mm)	Left
Model 1	+++	++	++	++	3	3	5	4 mm
Model 2	++	++	++	++	5	3	2	Not identified
Model 3	-	-	-	-	15	14	-	-
Model 4	-	-	-	-	14	15	-	-

++: Intermediate, +++: Pronounced, CT: Computed tomography

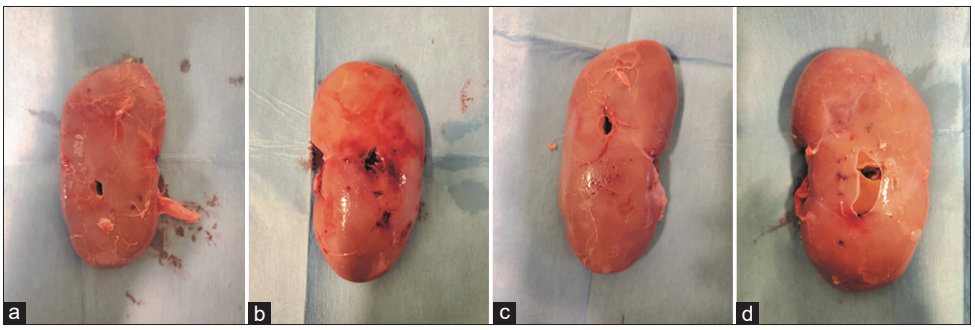

Figure 1: (a and c) Gross images of porcine kidneys that underwent two-step dilation and harvested immediately after the procedure showing tear-shaped defects. (b and d) Gross images of porcine kidneys that underwent gradual Amplatz dilation and harvested immediately after the procedure showing more rounded defects

the pyelocalyceal system and a 3-mm base toward the cortex. On the right kidney, a similar scar was identified with a diameter of 1 mm at its peak and a wider base accounting for 6 mm. Microscopically, intermediate fibrosis and inflammation accompanied a 3-mm scar tissue on the right kidney. Similarly, the left kidney carried signs of moderate fibrosis and inflammation [Table 2].

Imaging

In Specimen number 1, the immediate postprocedure CT scan revealed an 8-mm tract diameter on the right side (gradual dilation) and a 6-mm tract diameter on the left side (two-step dilation). Findings suggesting retro and intraperitoneal urinomas were described on both sides with no differences relative to the dilation method used. No damage to the renal vessels was reported in any side. The CT scan performed 15 days after the experiment revealed a 6-mm diameter cylindrical scar on the right kidney and a linear 5-mm wide one on the left [Figure 2a]. After contrast administration, both kidneys were enhanced homogenously, while no extravasation of contrast was evident. The last CT scan 4 weeks postoperatively identified a triangular scar with a 5-mm diameter near the pyelocalyceal system and a 3-mm diameter near the cortex on the right kidney. A 4-mm scar was visualized on the left side [Table 2]. The DMSA scintigraphy revealed no scar tissue in any kidney [Figure 2b].

Regarding Model number 2, the first CT performed after the procedure identified a 7-mm diameter tract on the right side, while on the left, there was a 5-mm tract. A small urinoma was reported on both sides but, in this case, the one on the left side was smaller. The renal vessels were intact. The second CT scan identified a triangular scar on the right kidney, measuring 2 mm near the peylocalyceal system, and 5–6 mm toward the cortex. On the left kidney, no evidence of scar tissue was found. No extravasation of contrast occurred on either side. On the last CT scan, 30 days after the operation, the scar on the right kidney appeared to be reduced in size, accounting for 2–3 mm [Table 2]. Again, DMSA scintigraphy showed no evidence of scarring.

DISCUSSION

The dilation of the access tract is one of the fundamental and most complex steps in PCNL.[5] The preferred dilation methods include Amplatz fascial dilation, metal telescopic dilation of the Alken type, balloon dilation, and "one-shot" dilation.[2] These methods have been compared in several studies[2,5-7] to investigate their effectiveness in the process of treating renal stones as well as their safety. Balloon and "one-shot" dilation have been reported to be the safest and most effective techniques for most cases[5,6] while requiring the least amount of fluoroscopy time.[2] The "one-shot"

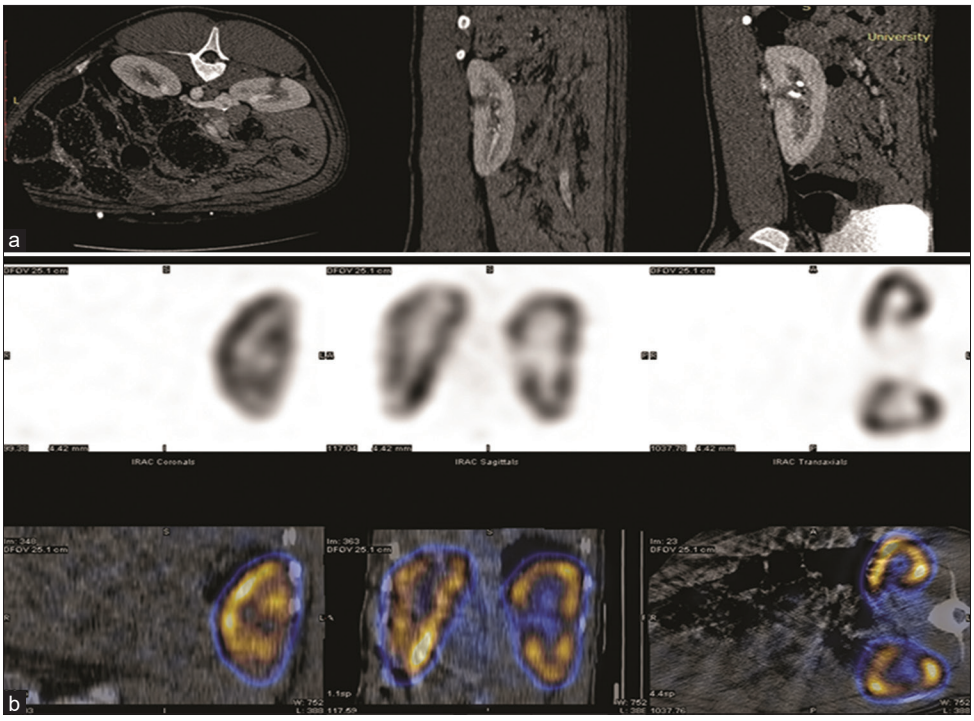

Figure 2: (a) CT scan performed on the animal 2 weeks after the PCNL procedure showing residual scarring of the access tracts. (b) DMSA and SPECT-CT scans were performed 1 month after the PCNL procedure showing no evidence of diminished blood perfusion in the kidneys. CT: Computed tomography, PCNL: Percutaneous nephrolithotomy, DMSA: Dimercaptosuccinic acid, SPECT-CT: Single-photon emission computed tomography-computed tomography

method given its low cost[2] and suitability for patients who have previously undergone renal surgery, in contrast with balloon dilation, is suggested as the preferable method.[6] However, its substantial risk of serious complications and lower successful dilation rate require the surgeon's technical expertise for the success of the procedure.[6]

In our practice, a two-step dilation technique using only 16 and 30 Fr dilators, following a nonpapillary puncture[1,4] has been successfully utilized in PCNL procedures. Despite the positive outcomes of the method we have observed, there is a lack of studies investigating its effects on renal tissue. In fact, to our knowledge, there is only one other study evaluating this specific dilation method published by Emiliani *et al*.[8] Consequently, the purpose of this study was to evaluate how this two-step dilation technique after nonpapillary puncture affects the severity of the renal trauma and the postoperative healing of the access site compared to standard gradual dilation (8–30 Fr), in porcine models. For the assessment pathohistological examinations supplemented by imaging tests (CT, DMSA scintigraphy, SPECT-CT) were performed on the operated kidneys, immediately and at different postoperative times.

The first CT scan performed immediately after the procedure, revealed similar trauma caused by the two dilation methods with the tract diameter being 2 mm smaller on the kidneys than two-step dilation was performed. As expected, the two follow-up CT scans (15 and 30 days postprocedure) visualized a progressive reduction in the size of the scars due to the healing process. The smaller-partly healed scars observed on the third postoperative CT scan may never completely recede since the injury caused by PCNL tract creation and dilation resembles a Grade 4 renal trauma.[9,10] Interestingly, the initial 5-mm tract observed on the left kidney of Specimen number 2, on which two-step dilation was used, had disappeared leaving no evidence of scar tissue on either of the follow-up CTs. This may suggest that this dilation method results in better healing of the access tract.

To accurately assess the impact of each dilation technique on scar formation and renal function, DMSA and SPECT-CT were conducted 1 month postoperatively. A previous study by Yalcinkaya *et al*., who performed DMSA 3 months postoperatively in patients undergoing PCNL, using balloon and metal dilation, reported no significant differences in scintigraphic parameters or glomerular filtration rate values.[11] Chatham *et al*. using mercaptoacetyltriglycine 3 renography concluded that by removing renal stones with PCNL, after gradual or balloon dilation, renal function is not only preserved but may even be improved.[12] In a study by Moskovitz *et al*., the total renal function of the operated kidney compared to the contralateral one was not affected by PCNL, as shown by QDMSA performed 1.5–2 years after the operation. However, a significant decline in the total functional volume of the operated poles was detected.[13] Similar findings were observed by Pérez-Fentes *et al*. who performed DMSA SPECT-CT scans on patients before and 3 months after PCNL with gradual dilation. They reported a minimal decrease on global renal function mainly near the site of percutaneous access but noted that the occurrence of postoperative complications could increase the functional impairment.[14] A comparative study by Unsal *et al*. investigated the impact of three different tract dilation methods on renal function including balloon dilation, metal dilation, and gradual Amplatz dilation using QDMSA.[15] In agreement with Chatham *et al*., kidney function was found to be stable and often improved post-PCNL, while the choice of dilation technique did not have a significant impact on the outcome.[12] In our study, DMSA scintigraphy scans revealed no evidence of scar tissue on any kidney regardless of the dilation method used, therefore, two-step dilation seems to have no significant negative effect on kidney function.

Gross examination of the kidneys harvested directly after the procedure revealed 14–15 mm defects on all kidneys regardless of the dilation method performed. On the right kidneys of the two pigs (gradual dilation), the defect was round-shaped, while on the left (two-step dilation), it was tear-shaped. These observations are in accordance with previous studies who conducted gross examinations on pig and cadaveric kidneys after PCNL tract creation and dilation.[8,16] However, Emiliani *et al*., who compared renal parenchymal injury using different dilation devices on porcine and cadaver models, reported a larger dilation area and diameter caused by two-step dilation than by Amplatz sequential dilation.[8] The cause of this difference might be the fact that in that study butcher bought kidneys were used, while we operated on living pig kidneys, which tend to be more solid and tense, and harvested them afterward.[8] Regarding the four kidneys harvested a month after the operation, significantly smaller scars were observed. On Specimen number 1, there was no noteworthy difference depending on the dilation method, but on Specimen number 2, the scar on the left kidney (two-step dilation) was almost half the size of the one on the right kidney (gradual dilation), again indicating a better healing process when using this method.

Histological evaluation of renal tissue harvested immediately after PCNL demonstrated similar results regardless of the

performed dilation technique, while injured areas were observed near the puncture site, despite the fact that the creation of the access tract was successful after only one puncture attempt. In the case of the kidneys which were allowed to heal for 30 days before harvesting, the grade of inflammation and fibrosis was evidently independent of the dilation method. In these specimens, the apparent angiogenesis, granulation tissue, and lack of dense collagen tissue indicated that the healing process of the scars was not yet finished.[17] In a similar study, Al-Kandari *et al*. compared the degree of renal trauma between Amplatz gradual dilation and balloon dilation in pig kidneys and reported similar acute and chronic effects on renal tissue by the two methods.[16]

One inherent limitation for *in vivo* studies using animals is the differences in anatomy. However, the porcine urinary system is the closest available model to human anatomy and harvesting of the kidneys for gross and histological evaluation of renal injury would not be possible on humans. Another criticism can be the small sample size. Nevertheless, we believe that using a total of eight kidneys was enough to demonstrate that the two-step dilation method used in our clinic does not negatively affect the degree of renal trauma or renal function compared to standard gradual dilation. Finally, in this study, the two-step dilation was assessed against only one of the standard dilation methods. Therefore, further investigation comparing more dilation techniques is required.

CONCLUSIONS

Our *in vivo* experimental study did not show any inferior outcomes of two-step dilation compared to the conventional gradual dilation method following a nonpapillary puncture regarding tissue damage. In fact, the postoperative CT scans and DMSA scintigraphy have shown a trend toward better healing and less scar tissue on the tract site when two-step dilation was utilized.

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Conflicts of interest
There are no conflicts of interest.

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