Experimental Model of Lower Pole Nephrectomy Using Human 3-Dimensional Endocasts: Analysis of Vascular Injuries

Luciano A. Favorito and Francisco J. B. Sampaio

OBJECTIVE To establish an experimental model for lower pole nephrectomy using 3-dimensional endocasts of human kidneys.

METHODS We studied 38 adult kidneys. The ureters, veins, and arteries were dissected and injected with yellow, blue, and red polyester resin, respectively. While the resins were still in a gel state, we performed lower pole guillotine sections at various distances from the hilar zone. The sample was divided into 4 groups: A, At hilar zone (11 kidneys); B, 0.5 cm from the hilar zone (12 kidneys); C, 1.0 cm from the hilar zone (8 kidneys); and D, 1.5 cm from the hilar zone (7 kidneys).

RESULTS A: At hilar zone—arteries: in 4 cases (36.36%), the lower segmental artery (LSA) was injured; veins: in 5 cases (45.45%), the lower venous trunk was injured (LVT). B: 0.5 cm from the hilar zone—arteries: the LSA was injured in 1 case (8.3%); veins: in 4 cases (33.3%), a lesion occurred to the LVT. C: 1.0 cm from the hilar zone—arteries: there were no lesions to LSA, but the infundibular arteries were damaged in all cases; veins: the interlobular veins were damaged in 3 of 11 cases (27.27%). D: 1.5 from the hilar zone—arteries: we observed lesions to the infundibular arteries in all cases; veins: arcuate veins were damaged in 4 of 7 cases (57.14%).

CONCLUSION Lower pole nephrectomies performed at less than 1.0 cm from the hilar zone presented a significantly high incidence of injuries to large arteries and veins.

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Partial nephrectomy is currently the preferred treatment for clinical T1 renal masses.[1] Partial nephrectomy is technically feasible and has an oncologic equivalency to radical nephrectomy and better functional outcomes.[2,3] Approaches for partial nephrectomy include open, laparoscopic, and robot-assisted surgery,[4-6] and robot-assisted partial nephrectomy is an emerging minimally invasive option for nephron-sparing surgery for localized renal tumors.[7]

To perform partial nephrectomy with a conventional, laparoscopic, or robotic approach, the most relevant issue is the understanding of the intrarenal anatomy.[8] Previous studies assessed quite well the intrarenal anatomy, becoming a base for various urologic procedures, including partial nephrectomy.[9-15] Accurate knowledge of the intrarenal anatomy and the use of experimental models are of great value to a better understanding and an adequate performance of partial nephrectomy.

Recently, upper pole nephrectomy in experimental models using human kidneys was studied with a precise analysis of vascular damage.[16] Anatomic and experimental studies of the lower pole of the kidney in humans are missing.

The aim of this work was to arrive at an anatomic model applied to lower pole partial nephrectomy to assess the distance away from the hilum that the posterior segmental artery, lower segmental artery, and lower venous trunk are at low risk of injury.

MATERIALS AND METHODS

The present work received approval from the State University of Rio de Janeiro Institutional Review Committee and was carried out in accordance with the ethical standards of the responsible Institutional Committee on Human Experimentation.

We studied 40 unfixed kidneys from 20 individuals who died of causes not related to the urinary tract. The material was obtained from autopsies performed within 6 and 12 hours after death.

We obtained 3-dimensional polyester resin endocasts of the pelvicaliceal system, together with the intrarenal vessels, according to previously described techniques.[9-16] In brief, the pelvicaliceal system was filled with yellow resin, and the arterial and venous trees were injected with red and blue resins, respectively.

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From the Urogenital Research Unit, State University of Rio de Janeiro, Rio de Janeiro, Brazil
Reprint requests: Luciano A. Favorito, M.D., Urogenital Research Unit, UERJ, Rua Professor Gabizo, 104/201, Rio de Janeiro-RJ, 20551-030 Brazil. E-mail: lufavorito@yahoo.com.br
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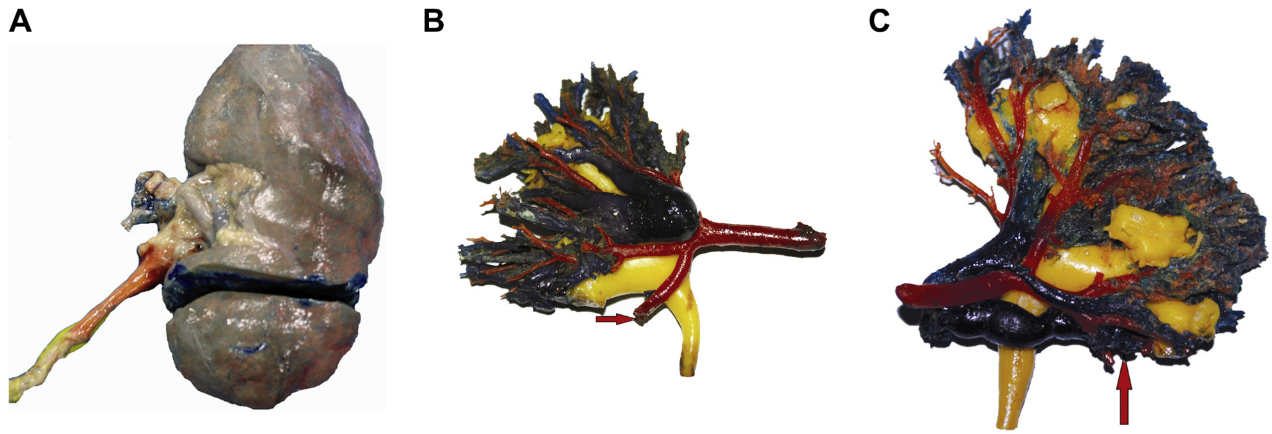

Figure 1. **(A)** Guillotine section in the lower pole of a human kidney that was injected with resin. A lower pole guillotine section was performed 1.0 cm from the hilar zone while the resin was still in a gel state. **(B)** Anterior view of a 3-dimensional endocast of a right kidney (pelvicaliceal system together with the intrarenal arteries and veins), sectioned at the hilar region, shows injury to the lower segmental artery (arrow). **(C)** Anterior view of a 3-dimensional endocast of a left kidney (pelvicaliceal system, together with the intrarenal arteries and veins), sectioned at the hilar region, shows injury to the lower segmental venous trunk (arrow).

After injection, the kidneys were cleaned to perform the following morphometric measurements: kidney length, upper pole width, inferior pole width, hilar width, hilar length, and thickness. All measurements were performed with a 0.01-cm precision caliper rule.

While the resin was still in a gel state, we performed lower pole guillotine sections at various distances from the hilar zone (Fig. 1A). Our sample was divided into 4 groups according to the site of section: (A) hilar zone: 11 kidneys, (B) 0.5 cm from the hilar zone: 12 kidneys, (C) 1.0 cm from the hilar zone: 8 kidneys, and (D) 1.5 cm from the hilar zone: 7 kidneys.

After polymerization and setting of the resin, the kidneys were immersed in commercial hydrochloric acid until total corrosion of the organic matter was achieved, and we obtained the 3-dimensional endocasts of the pelvicaliceal system together with the arterial and venous systems. We then examined the casts for damaged structures at the different section planes.

The structures evaluated for lesions were:

Arteries—lower segmental artery, posterior segmental artery (retropelvic), and infundibular arteries;

Veins—stellate, arcuate, infundibular, and main venous trunk.

To perform the contingence analysis of the population studied, we used the Fisher exact test ($P < .05$).

RESULTS

We found 38 kidneys (95%) with only 1 renal artery and 2 kidneys with 2 arteries (5%). These 2 kidneys with 2 renal arteries were excluded from the study. The arterial and venous lesions in the 4 groups studied are described below. Table 1 reports the incidence of vascular injuries at the various planes where the guillotine sections were performed.

Guillotine Section at the Hilar Zone

This group included 11 kidneys. Arteries: The posterior segmental artery was not damaged. In 4 cases (36.36%), the lower segmental artery was injured (Fig. 1B). All cases in this group presented injury of the infundibular arteries. Veins: In 5 cases (45.45%), the lower venous trunk was damaged (Fig. 1C). All cases in this group presented damage to the interlobular, arcuate, and stellate veins.

Guillotine Section at 0.5 cm from the Hilar Zone

This group included 12 kidneys. Arteries: The posterior segmental artery was not damaged. The lower segmental artery was injured in 1 case (8.3%; Fig. 2A). The infundibular arteries were damaged in all cases. Veins: In 4 cases (33.3%), damage to the lower venous trunk occurred (Fig. 2B). All cases in this group presented damage to the interlobular, arcuate, and stellate veins.

Guillotine Section at 1.0 cm from the Hilar Zone

This group included 8 kidneys. Arteries: The posterior segmental artery and the lower segmental artery were not damaged. In all cases, infundibular arteries were damaged. Veins: The lower venous trunk was not damaged. Interlobular veins were damaged in 3 of 11 cases (27.27%). All cases in this group presented damage to arcuate and stellate veins.

Guillotine Section at 1.5 from the Hilar Zone

This group included 7 kidneys. Arteries: The posterior segmental artery and the lower segmental artery were not damaged. In all cases, we observed damage to the infundibular arteries. Veins: There was no damage to lower venous trunk and interlobar veins. Arcuate veins were damaged in 4 of 7 cases (57.14%). All cases in this group presented damage to stellate veins.

Figure 3 shows a cast from a kidney with 2 arteries, demonstrating the arterial distribution in these cases.

COMMENT

Partial nephrectomy by laparoscopy or robotics is an efficient method, with the benefit of being minimally

Table 1. Incidence of vascular injuries at the various planes of guillotine section

Vessel	Hilum No. (%)	0.5 cm No. (%)	1.0 cm No. (%)	1.5 cm No. (%)
Retropelvic artery	0 (0)	0 (0)	0 (0)	0 (0)
Lower segmental artery	4 (36.3)	1 (8.3)	0 (0)	0 (0)
Infundibular artery	11 (100)	12 (100)	8 (100)	7 (100)
Lower venous trunk	5 (45.5)	4 (33.3)	0 (0)	0 (0)

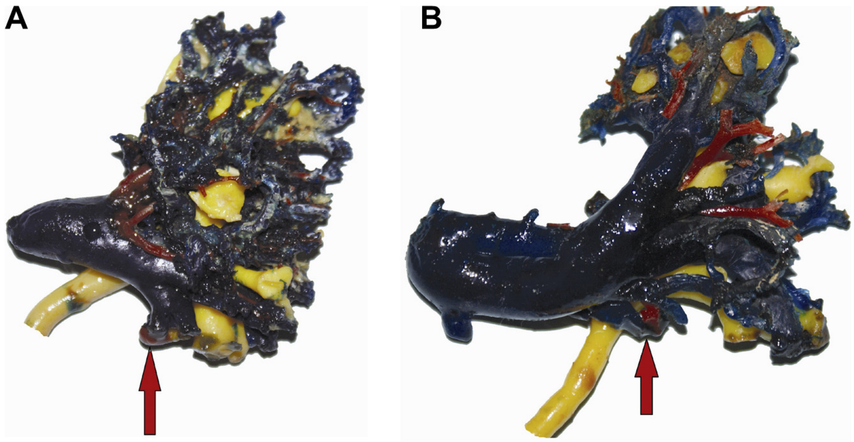

Figure 2. (A) Anterior view of a 3-dimensional endocast of a left kidney (pelvicaliceal system, together with the intrarenal arteries and veins), sectioned at 0.5 cm from the hilar region, shows injury to the lower segmental artery (arrow). **(B)** Anterior view of a 3-dimensional endocast of a left kidney (pelvicaliceal system together with the intrarenal arteries and veins), sectioned at 0.5 cm from the hilar region, shows injury to the lower segmental venous trunk (arrow). (Color version available online.)

invasive.[7,17,18] Partial nephrectomy performed in the superior pole may be associated with a great risk of injuring the posterior segmental artery.[14] Partial nephrectomy performed in the inferior pole presents fewer vascular problems than that performed in the superior pole.[14]

Perfect knowledge and identification of intrarenal anatomy may allow complete removal of the affected area, with maximal preservation of functioning renal parenchyma. Zero-ischemia robotic and laparoscopic partial nephrectomy, a novel concept, eliminates ischemia to the tumor-free healthy kidney.[19] A technique of anatomic vascular microdissection of renal artery branches is performed to selectively devascularize only the tumor, maintaining normal perfusion to the remaining kidney.[20,21] An understanding of the intravascular renal anatomy is one of the most important factors for performing these procedures.

Owing to the scarcity in medical literature of experimental models with human kidneys applied to lower pole partial nephrectomy, this report presents results that may serve as basis to assist this kind of intervention, indicating the spots where vascular lesions are more frequent and serious.

The main renal artery divides into segmental arteries near the renal hilum in 5 branches: posterior, apical, upper, middle, and lower anterior segmental arteries. The apical and lower anterior segmental arteries supply the anterior and posterior surfaces of the upper and lower renal poles, respectively, and the upper and middle segmental arteries supply the remainder of the anterior surface. The segmental arteries then course through the renal sinus and branch into the lobar arteries. Further divisions include the interlobar, arcuate, and interlobular arteries.[18,22]

In most cases, the arterial supply to the inferior pole originates from the inferior segmental artery of the anterior division. This vessel passes in front of the ureteropelvic junction and divides into an anterior and a posterior branch after entering the inferior pole.[10] The anterior branch is related to the anterior surface of the lower infundibulum, leaving its posterior surface free from arteries.[10] In this situation, the anterior and posterior aspects of the inferior pole are both supplied by a single artery (inferior segmental artery). In 37% of the cases, the anterior branch arose from the anterior division of the renal artery, and the posterior branch arose from its posterior division.[10,14] In these cases, the anterior branch supplies the anterior aspect of the inferior pole, and the posterior branch supplies its posterior aspect.[10,14] During partial nephrectomy in the lower pole, in addition to isolating and ligating the inferior segmental artery, it is important to perform careful dissection of the inferior portion of the retropelvic artery.[14]

In the experimental partial nephrectomies performed in this study, at the hilar region, we observed injuries to the inferior segmental artery in 36.3% but did not observe injuries to the posterior segmental artery. In experimental partial nephrectomies performed at 0.5 cm from hilar

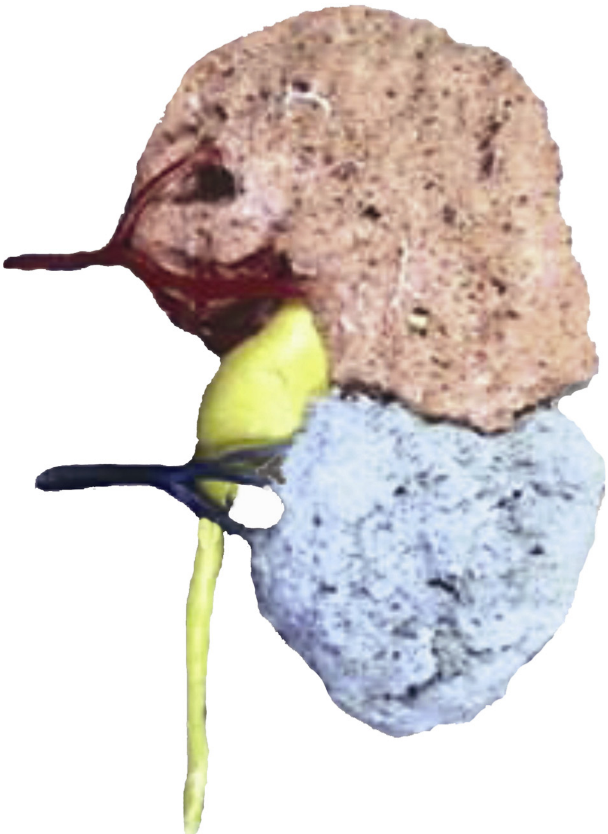

Figure 3. Anterior view of an endocast from a left kidney (pelvicaliceal system and arteries) with 2 arteries, injected with different colors of resin shows that the arterial systems are completely independent and that the inferior artery supplies the anterior and posterior surface of the lower pole. (Color version available online.)

region, we did not observe injuries to the posterior segmental artery arteries, and in only 1 case (8.3%) was the inferior segmental artery injured. Sections at the hilar zone are significantly hazardous, potentially leading to an inferior segmental artery lesion in up to 36% of the cases. In groups with sections performed at 1.0 and 1.5 cm from hilar region, we did not observe posterior segmental artery or inferior segmental artery lesions.

If the kidney is supplied by 2 renal arteries (8% of the cases), the inferior artery supplies the lower region of the kidney, without any communication with the superior artery (Fig. 3). Also in these cases, the inferior artery supplies the anterior and posterior aspect of the kidney, and therefore, the surgeon must not be concerned with the posterior segmental artery (retropelvic artery).[12] If a lower pole artery exists (5.3% of the cases), the procedure would be facilitated because the identification and previous ligature of these vessels is a simple procedure; also, this vessel supplies anterior and posterior surfaces of the kidney.

Concerning the collecting system, we found in a previous study[9] that all kidneys presented an individualized infundibulum draining the inferior pole with a number of calices, varying from 1 to 4 minor calices, with unique or fused papillae. The lower infundibulum would be long and thin, which would facilitate its identification, section, and closure, or would be short and thick, which would complicate its isolation.[9] These anatomic variants can be evaluated before surgery by imaging techniques.

Concerning the venous system, the renal cortex is drained sequentially by the arcuate veins and interlobar veins. The lobar veins join to form the main renal vein.[18] In 50% of the cases, the venous drainage of the lower pole is accomplished by 2 plexus located anteriorly and posteriorly to upper infundibulum, respectively.[11] In the other 50%, there was only the anterior plexus, being the posterior aspect of the lower infundibulum and free from important veins.[11] Theses veins also coursed close to the arteries of the inferior infundibulum.

In experimental partial nephrectomies performed at the hilar region, there were significant injury rates to the lower venous trunk (45%). In nephrectomies performed at 0.5 cm of the hilar zone, we observed lower trunk venous injury in 33%. We did not observe significant venous injuries in sections performed at 1.0 and 1.5 cm from the hilar zone.

The anatomic bases are very important during the performance of surgical interventions. Information about local anatomy and the probable place where injuries are more likely to occur is crucial to surgeons. The knowledge of the lower pole anatomy is of utmost importance for the performance of partial nephrectomy. Guillotine sections performed at hilar region and at 0.5 cm from the hilum presented a high incidence of injuries to the inferior segmental artery and lower venous trunk. Sections performed at 1.0 and 1.5 cm from the hilar region presented a low rate of injury.

CONCLUSION

In this experimental model, lower pole nephrectomies performed less than 1.0 cm from the hilar zone presented a significantly high incidence of injuries to larger arteries and veins. Nephrectomies at this level should therefore be performed with maximum care.

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APPENDIX

Supplementary Data

Supplementary data associated with this article can be found, in the online version, at 10.1016/j.urology.2013.07.026