Application of three-dimensional reconstruction of renal tumor vessels to guide laparoscopic partial nephrectomy of hilar tumors and non-hilar tumors under zero ischemia

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Research Article

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Abstract

Objective: To investigate the safety and efficacy of three-dimensional reconstruction of renal tumor vessels to guide laparoscopic partial nephrectomy of hilar tumors and non-hilar tumors under zero ischemia.

Methods: The clinical data of 82 patients with renal cancer who underwent zero ischemia retroperitoneal laparoscopic partial nephrectomy in the department of urology of our hospital from January 2018 to January 2021 were retrospectively reviewed. The patients were divided into hilar group and non-hilar group. The clinical data of all patients were statistically analyzed by t-test or χ².

Results: There was no significantly difference in gender, age, tumor diameter and pathological stage between hilar and non-hilar tumor group. Most of the target vessels in the hilar tumor group were single targets, while most of the target vessels in the non-hilar tumor group were multiple targets (P<0.05). There was no significantly difference between the groups for mean operative time and length of stay. But hilar tumor group had significantly longer operation time (109.3±9.2 vs. 90.3±9.5 min, p<0.001). There was no significant difference in renal GFR and serum creatinine between the two groups. Hilar tumor group had no significantly difference of change of creatinine and GFR at post-operative 6 and 12 months as compared with non-hilar tumor group. There were no bleeding, urinary leakage, infection and other related complications in the two groups after 1 month follow-up. After 12 months of follow-up, there was no tumor recurrence and metastasis in the two groups.

Conclusion: The application of three-dimensional renal tumor vascular reconstruction technology can better realize laparoscopic zero ischemia nephron sparing surgery. The target vessels of patients with hilar, single and early renal cancer are easier to find, which is more suitable for three-dimensional renal tumor vascular reconstruction technology to implement laparoscopic zero ischemia nephron sparing surgery.

1. Introduction

Renal tumor is one of the most common malignant tumors of urinary system, accounting for 3% of all malignant tumors. Its incidence rate increases at 3–4% per year, which is a serious threat to human health[1, 2]. Studies have shown that the incidence rate of renal tumors is increasing in the world. The proportion of early renal cell carcinoma and small renal cell carcinoma in renal tumors is increasing. Therefore, how to more effectively treat renal cell carcinoma, especially early renal cell carcinoma, has become one of the hotspots of scholars[3–5]. Nephron sparing surgery has long been the standard procedure for the treatment of early renal cancer because it has the same therapeutic effect as radical nephrectomy, and can reduce the incidence of postoperative chronic kidney disease and reduce the risk of cardiovascular and cerebrovascular complications and death caused by chronic kidney disease [6, 7]. In the process of traditional partial nephrectomy, it is necessary to temporarily block the main renal artery in
order to achieve a relatively blood-free operating environment and ensure the complete resection of the
tumor. However, excessive warm ischemia time will affect the function of other normal nephrons[8, 9].

Three dimensional reconstruction technology is to superimpose continuous two-dimensional images to
form a complete three-dimensional image through computer-aided design software. It was initially
applied to the industrial field, and then gradually expanded to the medical field [10–12]. Nowadays, many
scholars have reported that the application of three-dimensional reconstruction technology in traditional
partial nephrectomy can well display the relationship between tumor and kidney, preoperative tumor
location, and facilitate operation planning and preoperative Communication[13]. The above applications
are only relatively preliminary, and the application value in the surgical treatment of renal tumors is far
from being fully explored. The purpose of this study is to explore the establishment and improvement of
three-dimensional reconstruction and localization method of renal tumor target vessels, which can be
applied to laparoscopic zero ischemia nephron sparing surgery, in order to optimize zero ischemia
nephron sparing surgery and effectively protect the interests of patients.

2. Methods

2.1. Data collection

The clinical data of 82 patients with renal cancer who underwent zero ischemia retroperitoneal
laparoscopic partial nephrectomy in the department of urology of our hospital from January 2018 to
January 2021 were retrospectively reviewed. All patients were informed of the operation risk and signed
informed consent before operation. Institutional review board approval was obtained before initiating the
study.

Patient demographic data collected included age, gender, maximal tumor size and pathological stage.
Three dimensional renal tumor vascular reconstruction technique was used to evaluate the vascular
condition of renal tumor before operation. The operative outcomes including operation time, estimated
blood loss (EBL) and total length of stay. For functional outcome, creatinine level was collected at pre-
operative, post-operative 6 and 12 months. GFR of affected kidneys were collected at the same time
point.

Inclusion criteria: The patient was diagnosed as renal tumor by CT before operation, the R.E.N.A.L score
was less than 12, PADUA score was less than 14, and the tumor diameter was 2 ~ 7cm; Exogenous
growth; No previous anti-tumor treatment; No obvious distant metastasis of lung, liver and bone; There
was no previous history of abdominal and low back surgery. Exclusion criteria: Patients with obvious
anatomical abnormalities; History of operation in the operation area and other serious diseases of the
system; Those who lost follow-up or failed to check GFR after operation.

2.2. Surgical technique
All patients underwent renal CTA before operation to confirm tumor blood vessels and tumor conditions (Fig. 1A). Based on the DICOM data of the patient CTA, we applied computer software to process it into a three-dimensional image, and then corrected it jointly by imaging doctors, urologists and software engineers to construct a three-dimensional image (Fig. 1B and C). All operations were performed by the same group of surgeons.

After general anesthesia, the patient was placed on the healthy side, and the 3-channel method was adopted through retroperitoneum. The subcostal channel of axillary midline was increased according to the intraoperative situation. Both groups of patients were treated with free renal artery or branch of renal artery between psoas major muscle and perirenal fat capsule. Both groups were treated with "spherical coronal" partial nephrectomy. The operation was based on the three-dimensional reconstruction model of the tumor, and the appropriate surgical entry point was selected by using the target vessel localization method of renal tumor, and the "spherical coronal" resection of renal tumor was performed. Incise the renal capsule sharply at the junction of renal parenchyma and renal tumor about 3mm, and wedge into the renal parenchyma to find the transition zone between renal parenchyma and tumor pseudocapsule. If there is a lot of bleeding during the operation, we will use the auxiliary hole and insert the suction device to fully absorb the bleeding from the renal wound, so as to keep the visual field clear and assist in adjusting the direction of the tumor. According to the three-dimensional reconstruction model of renal tumor, we preliminarily determined the approximate orientation of tumor target vessels. When separating to the tumor target vessel, we used the combination of scissors and attractor to separate passively and sharply along the tumor capsule. When the tumor target vessels were completely exposed, we used Baig forceps or Hem-o-lok clamp to close and disconnect them. After the tumor was completely removed, the wound surface was examined. We used 2 − 0 barbed absorbable suture to suture the wound on the surface of the kidney. If there is a bleeding point, we use 3 − 0 barbed absorbable suture to stop bleeding. After checking that there is no obvious bleeding in the renal wound, we put the posterior abdominal drainage tube into the body, and then put the renal tumor specimen into the specimen bag and take it out. Finally, we closed the incision layer by layer (Fig. 1D-F).

2.3. Statistical analysis

The statistical analysis was performed by using IBM SPSS ver. 22.0 (IBM Co., Armonk, NY, USA). Median and \(\bar{x} \pm s\) were used for statistical description. Independent sample t-test and \(\chi^2\) Test was used for comparison between groups, with \(P < 0.05\) as the difference, which was statistically significant.

3. Results

Table 1 showed the summarized demographic characteristics data. There was no significantly difference in gender, age, tumor diameter and pathological stage between hilar and non-hilar tumor group. However, in the aspect of target vessels of renal tumor, most of the target vessels in the hilar tumor group were single targets, and one case was double targets. There were 45 patients with single target and 15 patients with multiple targets in the tumor group of other parts, and the difference was statistically significant (\(P < 0.05\)) (Fig. 2).
Table 1

Demographic characteristics

<table>
<thead>
<tr>
<th>Variables</th>
<th>Hilar tumor(n = 22)</th>
<th>Non-hilar tumor(n = 60)</th>
<th>t/χ²</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>male</td>
<td>13</td>
<td>37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>female</td>
<td>9</td>
<td>23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, years</td>
<td>51.4 ± 7.1</td>
<td>52.8 ± 6.1</td>
<td>0.881</td>
<td>0.381</td>
</tr>
<tr>
<td>Maximal tumor diameter, mm</td>
<td>39.4 ± 9.9</td>
<td>42.3 ± 9.6</td>
<td>1.202</td>
<td>0.233</td>
</tr>
<tr>
<td>Pathological stage</td>
<td></td>
<td></td>
<td>0.271</td>
<td>0.603</td>
</tr>
<tr>
<td>T1a</td>
<td>20</td>
<td>52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1b</td>
<td>2</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of target vessels</td>
<td></td>
<td></td>
<td>4.288</td>
<td>0.038</td>
</tr>
<tr>
<td>Single target</td>
<td>21</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiple targets</td>
<td>1</td>
<td>15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All the operations were successfully completed without conversion. 3 patients in the hilus group underwent nephron sparing surgery after blocking the renal artery, and the other 19 patients completed zero ischemia nephron sparing surgery without conversion to open surgery or radical nephrectomy. Among the non-hilar tumor group, 4 patients underwent nephron sparing surgery after blocking the renal artery, and the other 56 patients completed zero ischemia nephron sparing surgery without conversion to open surgery or radical nephrectomy. Table 2 showed perioperative data between two groups. There was no significantly difference between the groups for mean operative time and length of stay. But hilar tumor group had significantly longer operation time (109.3 ± 9.2 vs. 90.3 ± 9.5 min, p < 0.001).

Table 2

Comparison of perioperative data between two groups(x± s)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Hilar tumor(n = 19)</th>
<th>Non-hilar tumor(n = 56)</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean operative time( min)</td>
<td>109.3 ± 9.2</td>
<td>90.3 ± 9.5</td>
<td>7.591</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Median estimated blood loss(ml)</td>
<td>151 ± 25</td>
<td>145 ± 21</td>
<td>1.025</td>
<td>0.309</td>
</tr>
<tr>
<td>Length of stay(d)</td>
<td>7.3 ± 0.7</td>
<td>7.2 ± 0.9</td>
<td>0.441</td>
<td>0.661</td>
</tr>
</tbody>
</table>

Table 3 showed the results of renal function outcomes. There was no significant difference in renal GFR and serum creatinine between the two groups. Hilar tumor group had no significantly difference of change of creatinine and GFR at post-operative 6 and 12 months as compared with non-hilar tumor group. There were no bleeding, urinary leakage, infection and other related complications in the two
groups after 1 month follow-up. After 12 months of follow-up, there was no tumor recurrence and metastasis in the two groups.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Hilar tumor(n = 19)</th>
<th>Non-hilar tumor(n = 56)</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before surgery</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Serum creatinine(µmol/l)</td>
<td>74 ± 9</td>
<td>76 ± 8</td>
<td>0.912</td>
<td>0.365</td>
</tr>
<tr>
<td>GFR of affected kidney(ml/min)</td>
<td>42.7 ± 7.1</td>
<td>42.4 ± 6.7</td>
<td>0.166</td>
<td>0.868</td>
</tr>
<tr>
<td><strong>At 6 months after surgery</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Serum creatinine(µmol/l)</td>
<td>75 ± 7</td>
<td>79 ± 8</td>
<td>1.940</td>
<td>0.056</td>
</tr>
<tr>
<td>GFR of affected kidney(ml/min)</td>
<td>39.4 ± 5.6</td>
<td>41.2 ± 5.1</td>
<td>1.297</td>
<td>0.199</td>
</tr>
<tr>
<td><strong>At 12 months after surgery</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Serum creatinine(µmol/l)</td>
<td>74 ± 6</td>
<td>75 ± 7</td>
<td>0.557</td>
<td>0.580</td>
</tr>
<tr>
<td>GFR of affected kidney(ml/min)</td>
<td>41.8 ± 6.2</td>
<td>39.8 ± 7.8</td>
<td>1.013</td>
<td>0.314</td>
</tr>
</tbody>
</table>

4. Discussion

Traditional partial nephrectomy needs to temporarily block the main renal artery in order to achieve a relatively blood-free operating environment and ensure the complete resection of the tumor. However, too long warm ischemia time will affect the function of other normal nephrons[14, 15]. Scholars at home and abroad have put forward many methods to shorten the time of warm ischemia. On the basis of traditional laparoscopic partial nephrectomy, Baumert et al adopts the technology of early loosening the vascular blocking forceps, starts to suture the basal wound after tumor resection, then releases the vascular blocking forceps, and then uses the method of hemostatic gauze to fill the wound and absorbable thread to continuously suture the renal parenchyma and capsule, which shortens the warm ischemia time by nearly 50%[16]. Shao et al blocked the branches of renal artery by segments, resulting in thermal ischemia of a small part of normal tissues at the tumor site and around. The nephron sparing operation was completed when the blood perfusion of other renal tissues was normal. The recovery of postoperative renal function of patients with this method was better than that of patients with main artery occlusion[17]. Gill et al separated and blocked the renal artery branch supplying the tumor during the operation, cooperated with intraoperative ultrasound to determine whether the blood supply of the tumor was completely blocked, and reduced the patient's arterial blood pressure to 60mmhg when cutting to the deepest part of the tumor. Under this condition, partial nephrectomy was completed, and the recovery of renal function of the patient was significantly improved [18].
Gill first proposed the concept of zero ischemia laparoscopic partial nephrectomy[18]. They tried to eliminate total renal ischemia by careful microanatomy of the renal artery branches supporting the tumor[6, 19]. However, dissecting the tumor blood supply artery from the hilum is technically difficult and time-consuming[20, 21]. It is very important to clarify and understand the anatomy of tumor and renal vessels before operation, especially the intrarenal relationship between tumor and blood supply artery.

These techniques not only ensure the complete resection of the tumor, but also effectively protect the patient's renal function. However, these techniques are difficult and can only be used by skilled surgeons. Moreover, the only data that can evaluate the tumor before operation is CTA, which can not accurately evaluate the renal tumor and tumor blood vessels, which makes the operation more difficult.

Three dimensional reconstruction technology is to superimpose continuous two-dimensional images to form a complete three-dimensional image through computer-aided design software. It first appeared in the 1980s and 1990s, and was initially used in the industrial field, and then widely used in the medical field with its unique advantages[11, 22]. In 2014, Silberstein et al successfully printed the world's first kidney model with tumor. This model is consistent with the size of the patient's kidney, with the main renal vascular structure, renal pelvis and proximal ureter, and the situation of renal tumor is clearly visible[23]. Bernhard et al. Printed customized kidney models with tumor for 7 patients before partial nephrectomy, which improved the understanding of doctors and patients on tumor characteristics by 39.3% and the understanding and acceptance of operation methods by 44.6%. It can be seen that three-dimensional reconstruction technology is not only beneficial to surgeons, but also provides a good tool for patient education and doctor-patient communication[10].

Based on the three-dimensional renal tumor vascular reconstruction technology, we evaluate the renal tumor vessels in detail before operation and accurately locate the renal tumor target vessels, so as to optimize the surgical treatment scheme and deal with the tumor target vessels more accurately. This truly realizes laparoscopic zero ischemia nephron sparing surgery.

In this study, there were 4 patients with T1b renal cancer in the lower pole of the kidney in the non-hilar tumor group. The preoperative three-dimensional renal tumor vascular reconstruction technology evaluated that the tumor vessels were multi-target. It was planned to block LPN without renal pedicle. As a result, the intraoperative bleeding was obvious. After blocking the renal artery, nephron sparing surgery was performed. Laparoscopic nephrectomy was successfully performed in the remaining 56 patients. In the hilar tumor group, there were 3 patients with stage T1b renal cancer, of which 1 patient had double target tumor vessels. During the operation, 3 patients had obvious bleeding. Therefore, the renal artery was blocked halfway for nephron sparing surgery, and the other 19 patients successfully completed zero ischemia laparoscopic partial nephrectomy. No postoperative complications such as urinary leakage and bleeding occurred in both groups. The postoperative follow-up results showed that there was no positive margin and local recurrence.

We analyzed the target vessels of renal tumors in patients. The results showed that most of the tumor vessels in the hilum of the kidney were single targets, while there were more tumor targets in other parts,
especially when the tumor diameter was large, the vessels were often multi-target. In this study, 4 patients with non hilar renal tumors underwent renal artery occlusion due to more intraoperative bleeding. The tumors of these four patients were located in the upper pole, and the tumor diameter was more than 4cm, so there were more tumor vascular targets. Compared with the target blood vessels of renal bipolar tumors, the target blood vessels of renal hilar tumors are mostly single, and the target blood vessels of renal hilar tumors are thicker, which makes it easier to find and complete blocking during the operation, indicating that the localization method of renal tumor target blood vessels is particularly suitable for patients with single early renal cancer in renal hilar.

We applied the three-dimensional renal tumor vascular reconstruction technology to better realize the laparoscopic zero ischemia nephron sparing surgery, reflecting the clinical value of precision medicine. While completely removing the renal tumor, we protected the renal function of the residual nephron to the greatest extent and reduced the possibility of postoperative renal insufficiency, so as to avoid renal replacement therapy and save social resources. However, not all cases of renal tumor are suitable for this technology. When implementing the target vessel localization method of renal tumor in clinical practice, the following points should be paid attention to: 1) when selecting patients with exogenous tumor, it is recommended that the proportion of exogenous tumor body should be more than 50%, and the straight diameter of tumor should be 2 ~ 5cm; 2) This method is recommended for single tumor and hilar tumor; 3) In order to avoid too much intraoperative bleeding that cannot be controlled, it is recommended to routinely separate and treat the renal pedicle vessels in advance.

The present study has some limitations. First of all, our cohort is a retrospective study and the patients were electively received laparoscopic partial nephrectomy under zero ischemia according to surgeon's preference. Secondly, the diameter of renal tumors in this study was small, the technique's efficacy and safety in the treatment of larger renal tumors remains unknown. Third, robotic assisted nephron sparing surgeries were preferred for the treatment of T1b and other complex renal tumors to facilitate tumor resection during zero-ischemia partial nephrectomy, but we are lacking of this experience. Furthermore, this was a single-center retrospective study with small sample size and short-term follow-up results, thus larger sample size study and long-term follow-up outcomes would be required in near future to confirm our findings.

In conclusion, three-dimensional renal tumor vascular reconstruction technology could not only provide adequate information about anatomical interrelationship between tumors, renal vasculature and collecting system, but also identify the number and location of tumor feeding arteries clearly. In retroperitoneal laparoscopic partial nephrectomy, for some optional cases, the application of three-dimensional renal tumor vascular reconstruction technology can better realize laparoscopic zero ischemia nephron sparing surgery, which is feasible and safe. The target vessels of patients with hilar, single and early renal cancer are easier to find, which is more suitable for three-dimensional renal tumor vascular reconstruction technology to implement laparoscopic zero ischemia nephron sparing surgery.

Declarations
Conflict of interest

These authors declared no conflicts of interest in this work.

Fund Project

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References


**Figures**
Figure 1

Application of target vessel localization of renal tumor in zero ischemia laparoscopic partial nephrectomy
Figure 2

Comparison of target vessels of renal tumors in different parts