International Journal of Surgery 18 (2015) 48–54

Contents lists available at ScienceDirect

International Journal of Surgery

journal homepage: www.journal-surgery.net

Review

Achieving zero ischemia in minimally invasive partial nephrectomy surgery

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HIGHLIGHTS

- Seven methods could achieve zero ischemic partial nephrectomy.
- Selective renal artery clamping technique is suitable for medially located tumors.
- Selective renal parenchymal clamping technique is achievable for polar tumors.
- Energy ablative techniques like laser and radio frequency could also achieve zero ischemia MIPN.

ARTICLE INFO

Article history:
Received 1 October 2014
Received in revised form
24 March 2015
Accepted 11 April 2015
Available online 17 April 2015

Keywords:
Minimal invasive partial nephrectomy
Robotic partial nephrectomy
Renal function protection
Zero ischemia
Energy ablative surgery

ABSTRACT

Widespread application of the minimally invasive partial nephrectomy (MIPN) techniques like laparoscopic and robotic partial nephrectomy, has been limited by concerns about prolonged warm ischemia. So techniques aiming at performing have been actively explored. A systemic review of literatures on the MIPN without hilar clamping was performed and related methods were summarized. There are mainly seven methods including selective/segmental renal artery clamping technique, selective renal parenchymal clamping technique, targeted renal blood flow interruption technique, laser supported MIPN, radio frequency assisted MIPN, hydro-jet assisted MIPN, and sequential preplaced suture renorrhaphy technique that have been undergoing enthusiastic investigation for achieving MINP without hilar clamping. All of these emerging techniques represent the exploring work to achieve a zero ischemia MIPN for small renal tumors of different characteristics. Though not perfect for any of the technique, they deserve a further assessment during their future experimental and clinical applications.

1. Introduction

The incidentally discovered small renal tumor, especially renal cell carcinoma, has been increasingly found for the past several decades due to the availability of medical services, the use of novel sensitive imaging procedures and the prevalence of etiologic risk factors [1]. Surgical extirpation is considered the only curative treatment for these incidentomas for their possible malignant properties. While radical nephrectomy, which inevitably decreases renal reserve and sequentially exposes the patient to greater cardiovascular morbidity and mortality risks [2], is increasingly considered an overtreatment for the majority of these masses. Nephron sparing surgery (NSS) has gained wider acceptance for its equivalent oncologic efficacy and superior functional protection compared with radical nephrectomy [3,4]. With the advent of minimally invasive surgery era, laparoscopic partial nephrectomy (LPN) and robotic partial nephrectomy (RPN) have become the preferred options though technically challenging. A bloodless field is necessitated during these so called minimally invasive partial nephrectomy (MIPN) methods so as to allow precise tumor excision, surgical closure of the collecting system and re-approximation of parenchyma-defect as well as to avoid excessive intraoperative blood loss [5]. Traditionally, blocking renal blood flow by hilar vascular clamping is the standard of care routinely performed for achieving a bloodless intraoperative visualization [6]. Thus, either warm or cold ischemia is employed during partial nephrectomy for the whole involved kidney. However, a criticism of MIPN has been its potential longer ischemia time [7]. Recent study indicated that every minute of ischemia imparted additional risk for

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http://dx.doi.org/10.1016/j.ijsu.2015.04.046
1743-9191/

postoperative renal dysfunction [8]. Especially, old or predamaged kidneys often fail to compensate the renal ischemic injury. Warm ischemia is considered as the most important surgically modifiable factor governing the return of renal function postoperatively [9]. Moreover, hilar clamping adds time constraints on the surgeons [10,11], which makes the already challenging procedure a much more difficult one.

The term "zero ischemia" in MIPN implies that tumor resection and renorrhaphy were successfully completed without hilar clamping and thus not subjecting the whole involved kidney to ischemic stress [12]. We sought to offer a comprehensive and updated review of the current available techniques that could achieve zero ischemia MIPN.

2. Evidence acquisition

We carried out a review of the literature in MEDLINE database, using a free-text protocol with the terms "renal cell carcinoma", "renal tumors", "partial nephrectomy", "nephron sparing surgery", "zero ischemia", "off clamp", "laparoscopic", "robotic assisted" across the title and abstract fields of the records without limits. Two authors (HW and JZ) separately reviewed all the retrieved abstracts and selected the papers reporting technique involved minimal invasive partial nephrectomy performed without hilar clamping. In a second step analysis, we carefully examined the full-length articles, especially the introduction part and discussion part, to select other significant studies cited in the reference lists of the selected papers. For some selected techniques we even performed another search in MEDLINE using unique terms like "selective renal artery clamping", "segmental renal artery clamping", "renal parenchymal clamping", "superselective embolization", "temporary targeted renal blood flow interruption", "hydro-jet technology", in combination with some of the previous used terms. Any discrepancy was resolved by open discussion. Globally, at the end of the review process, a total of 46 representative papers were selected and discussed in the present review.

3. Evidence analysis

Contemporary minimal invasive partial nephrectomy includes a spectrum of surgical techniques that could achieve the zero ischemia; we classed all these techniques into methods and discussed them as follows:

3.1. Selective/segmental renal artery clamping technique

Selective/segmental renal artery clamping technique is based on the concept of anatomic renal arterial branch microdissection and super-selective bulldog clamping to achieve tumor-specific devascularization and thus achieving "zero ischemia" for the preserved remnant kidney tissue [13]. The concept of this technique was first introduced by Nohara T and colleagues in 2008 as a modified form of anatrophic partial nephrectomy [14]. Then Benway BM and colleagues confirmed its effectiveness in improving functional outcomes during kidney surgery [15]. But it was Gill IS that vigorously developed the procedure as a feasible and attractive method to protect renal function during LPN [13,16].

There are several critical steps for successfully performing this procedure. Firstly, the feeding branch for tumor is identified by angiographic evaluation [17] or computed tomography angiography (CTA) [18]. These image techniques could precisely guide the clamping of tumor-supplying branches during MIPN so that decreasing the risk of vessel injury and blood loss [18,19]. Then followed is microdissection of renal arterial branches. Intraoperative complications like injuries of the renal vein or its accessories would occasionally happen for most laparoscopic urologists during this step [20]. But nowadays with the three-dimensional stereoscopic magnification and intuitive movements of the robotic EndoWrist instruments in the robotic era, tertiary and even quaternary arterial branches clamping have been relatively easily achievable [16,21]. Tumor resection is carried out after tumor devascularization was superselectively performed by neurosurgical aneurysm microsurgical bulldog clamps [22] or even conventional laparoscopic bulldog clamps [23]. However, the procedure requires deft suction irrigation and technical facility with suturing since some bleeding does occur due to the patent renal vascular [16].

The merits and drawbacks of the selective/segmental renal artery clamping technique compared with the traditional method were investigated enthusiastically. Desai MM and colleagues compared the perioperative outcomes of superselective vs. main renal artery control during robotic PN. Performed on patients with larger tumors (3.4 vs. 2.6 cm, $p = 0.004$), more commonly hilar locations (24% vs. 6%, $p = 0.009$), and more complex positions (PADUA 10 vs. 8, $p = 0.009$), the robotic tumor-specific devascularization method achieved more encouraging results: less decrease in eGFR at discharge (0% vs. 11%, $p = 0.01$) and at last follow-up (11% vs. 17%, $p = 0.03$) [21]. And according to Ng CK and colleagues, the paramount merit of this technique is its ability to treat technically challenging tumors like deep parenchymal, central or hilar tumors, which often bears higher-order arteries immediately supply the tumor [24]. For patients with a laterally based tumor, it is less likely to identify a dedicated arterial branch for the increased intraparenchymal distance between the main renal artery and the tumor. Additionally, larger, laterally based tumors often have multiple arterial feeding sources, rendering these tumors less suitable for this technique. In other words, peripherally located tumors would attain a compromised benefit of the technique [21,24].

3.2. Selective renal parenchymal clamping technique

Selective renal parenchymal clamping technique achieves regional ischemia via compressing renal surface. Compared with the above selective/segmental renal artery clamping technique, this technique restricts the ischemia to renal tissue close to the tumor in a much simpler, in other words, much rougher fashion. Though having been proposed for more than 20 years, this technique has never gained its prevalence [25].

The parenchymal clamping could be performed by various tools. The cable-tie and modified tourniquet-type devices have been used clinically with varied success in early reports [25–27]. However, the present most popular instrument for selective parenchymal clamp in laparoscopic and robotic environment is Simon Clamp, which was firstly introduced by Simon J and his team in 2009, mimicking the shape of the Nussbuam clamp [28]. The device allows for equal distribution and constant maintenance of the pressure on the kidney, resulting in no bleeding from the resection site as well as no tearing of the renal capsule [29–31]. This technique also has the advantage of achieving good access to the tumor and supporting the surgical procedure [32].

There are studies comparing the parenchymal clamping technique with haliar clamping which encouraging us. Hsi RS and colleagues designed the comparative research in a group of patients undergoing robotic-assisted laparoscopic partial nephrectomy. The results showed that a better preservation of immediate post-operative GFR from baseline to postoperative day 2 (median ΔGFR 0 vs. −18 ml/min/1.73 m(2), $P = 0.02$) was achieved [32]. But one main concern for this technique is the slipping of the device from the kidney surface, which could result in huge loss of blood and endanger the patient. Another is that much more extra healthy renal tissue, which was proved to be significant for long-term renal