Kidney Clamp for Laparoscopic Partial Nephrectomy

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Abstract

As a result of new imaging methods over the past few decades, there has been an increase in carcinoma detection in the kidneys resulting in an overall increase in nephrectomy surgeries. Recently, surgeons are performing more partial nephrectomy surgeries versus radical nephrectomy surgeries in order to spare viable and functioning tissue. In addition, these surgeons are excising over from open surgeries to laparoscopic surgeries in order to decrease post-operative complications. However, current methods of blood flow occlusion for laparoscopic partial nephrectomy (LPN) create global ischemia in the kidney that may lead to long term loss of renal function. Our client, an LPN surgeon, would like us to develop a device that can occlude blood flow in the kidney at the site of the partial nephrectomy, in efforts to simplify the procedure and prevent tissue damage. The device will clamp across the kidney in order to occlude renal blood flow to the tumor reducing the chance of global ischemia in the kidney, therefore, resulting in less complications.

Background

The Kidney:
- Filters around 20% of body’s blood per minute.
- Blood flow rate essential to maintain homeostatic functions (i.e. remove wastes).
- Renal cancer is the 7th leading malignant condition for men, 12th leading among women in US.
- Nephrectomy is initial treatment for majority of patients
- 1/3 of patients who undergo nephrectomy will have a recurrence.

Laparoscopic Partial Nephrectomy:
- Removal of only diseased tissue from kidney.
- Clamping needed to control blood loss and keep operating view clear.

Current Method
Occludes blood supply to entire kidney causing cell death (global ischemia) by clamping at the source of blood flow. Can cause loss of kidney function if ischemia for greater than 30 minutes.

Proposed Method
Selective occlusion blood flow to the portion of the kidney being removed (regional ischemia) by clamping around the functional part of the kidney, or parenchyma.

Motivation

- Renal cancer is the 7th leading malignant condition for men, 12th leading among women in US.
- Nephrectomy is initial treatment for majority of patients
- 1/3 of patients who undergo nephrectomy will have a recurrence.
- Clamping times of as little as 30 minutes have been shown to cause 10% loss in kidney function post-surgery.

Design Specifications

- Must be able to fit through a 12 mm by 15 mm trocar
- Flexible shaft
- Provide enough strength to occlude renal blood flow
  - Without causing harm to kidney
  - Adjustable force
  - Malleable force
  - Easily distributed force
  - Maintain force for 5–30 minutes
  - Provide force 5 N or less
- Reusable
  - Able to operate with one hand
  - Accommodate hand breadth ranging from 6.5 – 9.5 cm
  - Not exceed cost of commercially available clamps ($500)
  - Entire clamp should weigh less than 5 lbs.

Future Work

- Convexity of clamp to interact with surface of the kidney.
- Based on our results the total width of the clamp when compressed will be 11 mm, therefore it will fit through the trocar.

Final Design

- Clamp: Made from spring stainless-steel
  - 1.75 mm x 6 mm x 110 mm²
  - Maximum 12 mm width when closed
  - Designed for use in 12 mm trocar

- Arm: 100 mm length
  - 8 mm inner diameter
  - 10 mm outer diameter
  - 600 mm length
  - 1.75 mm x 6 mm x 110 mm²

- Handle: Ratchet to lock into place
  - Connected to clamp through wire and bike brake

Clamps Using a Load-Cell Device – Are All Clamps the Same?

Yield Strength of Stainless Steel (ferric): 172 MPa
- 95% greater than our highest experimental stress

Design Analysis

- 5 N Load
  - Deformation (mm): 2
  - Stress (kPa): 44

- 20 N Load
  - Deformation (mm): 12
  - Stress (kPa): 79

Results

- Tension
  - 5 N Load: 12
  - 20 N Load: 12

- Compression
  - 5 N Load: 11.5
  - 20 N Load: 11.5

- Tension
  - 5 N Load: 44
  - 20 N Load: 179

- Compression
  - 5 N Load: 45
  - 20 N Load: 181

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References


Figure 1a (left) shows the current method of tumor removal with clamps applied at the blood source. Figure 1b(right) shows the proposed method, which employs a clamp around parenchyma. Figure 2 shows the variation of force generated by current clamps on the market. The inlaid picture shows an example of the texture desired to stabilize the kidney.

Figure 3 shows the handle for our final design.

Figure 4 shows a Solidworks model of our clamp and arm.

Figure 5 shows Solidworks stress analysis of the curved clamp. One end was fixed as a pin while the other was fixed as a roller. Force was applied evenly across the surface of the clamp with different loads.

Figure 6 shows the handle for our final design.

Figure 7 shows the variation of force generated by our clamp on the market. The inlaid picture shows an example of the texture desired to stabilize the kidney.

Figure 8 shows a Solidworks model of our clamp and arm.