Sutureless End to End Ureteral Anastomosis Using a New Albumin Stent and Diode Laser

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ABSTRACT

Sutureless end to end ureteral anastomoses was successfully constructed in acute and chronic experiments. A photothermal sensitive hydrolyzable (PSH) albumin stent played roles as solder and intraluminal supporter to adhesion and position the anastomosed ureter by end to end fashion. The anastomosis seam was lased with 810 nm diode laser energy supplied through hand-held 600 μm noncontact optical fiber. A continuous 1 watt wave of power was applied for laser anastomosis. Integrity, welding strength, bursting pressures of anastomosis and histological reaction, and radiological phenomena were compared to those of anastomoses constructed using a liquidity soldering technique. The acute results of two methods were equivalent at welding strengths, but the liquid soldering showed more energy consumption. At chronic study, the radiological and histological studies were performed to evaluate the complications of the anastomosis. Excellent healing and varied degrees of complications were observed. We conclude that PSH stent showed great promise for ureteral anastomosis using laser welding.

Keywords: Ureteral Stent, Ureter, Diode Laser, Laser Welding, Albumin, Solder, Laser Soldering, In Vitro, In Vivo, Swine

1. INTRODUCTION

Advances of laser tissue welding in urinary tract repair are able to provide a rapidly watertight seal and avoid potential lithogenesis caused by conventional sutures and staples. However, some problems have limited the clinical use of this technology, such as unreliable fusion strength, thermal damage of welded tissue and lack of a standard reference endpoint during welding procedures. During the past decade, the application of laser solders has greatly increased the bonding strength of laser fusion (1). Several studies have demonstrated that the welding strength of laser tissue soldering depended on solder protein concentration (2, 3). But, the technical problem that still remains is the precise seromuscular apposition of tubular organs for accurate placement of the laser spot and uniform layering of the solder on the fusion surface during laser welding procedures (4).

In this study, a new biocompatible, water-soluble and photothermal sensitive (PSH) stent made by albumin and ICG was designed for ureteral end to end anastomosis in fashion using laser welding techniques. The ureteral ends were supported intraluminally by the stent for precise end to end apposition and were welded by denatured albumin. The laser irradiation part of the stent will be denatured by laser heat and formed a solid ring to bind and approximate the vessel edges. The undenatured albumin stent component is dissolved by urine fluid immediately. In vitro and in vivo experiments were designed to evaluate the feasibility of ureteral anastomosis using the PSH stent and diode laser welding.

2. MATERIALS AND METHODS

2.1. Preparation of PSH Stent and Solder

25% Human serum albumin (Michigan Dept. of Public Health, U.S. license No.99, MI, USA) was filtered through an Ultrafiltration Cell (Amicon, Model 8400, MA, USA) to concentrate it to 50% by weight. 10mM Indocyanine Green (ICG) (Sigma, I2633, MO) solution was added to 50% albumin at 1:100 by volume and mixed well for 3 min. The mixture was air blow until the solvent evaporated and became moldable. The moldable albumin was molded to a hollow stent with outer diameter of 3.5 mm, inner diameter of 2.0 mm and 1.5 cm in length. The procedure was performed using sterile techniques. The stent was sterilized by γ-radiation and stored at –4 C and under light-free conditions until use (Fig 1). The liquid solder was made of 50 % albumin with 0.1 mM ICG that was made similar to the photothermal sensitive stent without drying procedures. The solder was stored in a 1ml syringe at –4 ^{0}C and under light-free conditions until use.

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2.2. Laser System

Laser treatments were performed with a diode laser module (Diomed 25, Diomed Limited, Cambridge, UK) coupled to a quartz silica non-contact fiber optic (600-μm diameter). The laser system consists of a phased array of gallium-aluminum-arsenide semiconductor diodes, and the major wavelength output of the diode laser is 808 ± 1 nm. Additional bands of laser energy occur in the visible red spectrum and allow the operator to visualize the spot size of the laser during activation. The spot diameter was ~ 1 mm at a distance of ~ 2 mm. Laser power was measured and recorded at the out of the optic fiber with a built-in laser meter monitor. The maximum diode power output is 25 W. The laser was used in continuous wave mode with 1 W output.

2.3. In Vitro Study

Fresh ureter segments were harvested from domestic swine with minimal trauma and immediately placed in sterile 0.9% saline solution at –4 ^{0}C. The study was divided into two groups. In group 1, 12 ureters were completely transected and were reanastomosed end to end using PSH stent laser fusion (Fig. 2a,b). In group 2, 12 ureters anastomosis were performed using laser liquid solder technique. Each ureter was carefully placed over and tied on a stainless steel tube with 1-0 silk tie to prevent sliding. The stainless steel tube was connected in parallel to an infusion pump (Syringe infusion pump 22, Harvard apparatus, MA) and pressure recorder (Pressure Monitor 4, Living System Instrumentation, VT). The ureteral stumps were spatulated and opposed using two 6-0 vicyl suture. During PSH stent laser welding, the two ends were pulled over the PSH Stent to approximate in an end to end fashion. While working on liquid solder welding, the ureteral ends were pulled over a 3.5 mm. OD. balloon catheter for end to end apposition. The solder was applied in a thin coat on the seam before laser welding. The solder covered approximately 1 mm on each side of the anastomosis. The holding suture material melted away with laser welding. The samples were treated for burst pressure and tensile strength testing.

2.4. Burst Pressure and Tensile Strength Measurements

A perfusion system was set up between the welded vessel and infusion pump for burst pressure testing. A 0.9% NaCl with 1% Methylene blue solution was infused at 2ml/min flow rate to dissolve the PSH stent and check up for leaks of anastomotic site. After the stent was dissolved, the pressure recorder switch was turned on to record welding burst pressure. The expandable balloon catheter was deflated and removed carefully from welded vessel using laser welding. The ureters were perfused for an hour and then the burst pressure (mmHg) was recorded. While the vessel didn't break during the burst pressure testing were sent for histological examination. The welded ureters were soaked in 37 ^{0}C saline solution overnight and then tested for tensile strength. The breaking force of the laser weld was recorded using a tension tester (Vitrodyna V1000, Liveco, VT). The standard load weight was 5000 g.

2.5. In Vivo Study

Six domestic female swine, weight 30-40 lbs., were studied in this project. The surgical protocol followed guidelines for the care and use of the laboratory animals and was approved by the Animal Care and Use Committee of Oregon Health Sciences University.

The animal was sedated with an IM injection of Telazol 1.5 ml followed by general endotracheal anesthesia, using 1-2% Halothane inhalant. Heart rate and oxygen saturation was monitored during the surgery. The animal was positioned supine, and shaved and prepped in a sterile fashion. The paramedian retroperitoneal approach was made from fourth nipple to below the last nipple.

A 3 cm of the mid-segment of both ureters were exposed and mobilized to cut off in spatulate fashion. On the right side, the PSH stent was placed into ureteral lumen with a 4.8 Fr. x 18 cm double J ureteral stent inserted through the PSH hollow stent and graft (Circon Surgitek, CA). The double J was placed through free ureteral stumps into renal pelvis above and the bladder below. Then the ureteral stump was pulled over the PSH stent. On the left side, the ureter was reconstructed with the liquid solder and a 4.8 Fr x18 cm double J ureteral stent was remained in lumen. The solder covered approximately 1 mm on ureteral edge. A 12 Fr. urethral catheter was placed through urethra output from bladder. The bladder and abdominal incision were closed in a standard fashion using a running 3-0 chromic suture after making sure no leakage or bleeding was present at the anastomotic sites. The catheter was sutured to the animal's perineal skin and cut short to allow chronic urine drainage and was removed at 1 week after surgery.

The animal was maintained on antibiotics for 14 days (Ampicillin and Getamycin). The animals were schedule sacrificed at 3 hour, 1, 2, and 4 weeks., The excretory and retrograde urography were performed before sacrificed. The double J was removed before retrograde urography. Then ureter was harvested for histology.

2.6. Histological Study

The tissue samples were immediately fixed in 10% formallin solution. Then the specimens were embedded with paraffin wax and sliced. Trichrome, VVG, Von Kossas, Actin and H & E staining were performed to study collagen, elastin, calcification and smooth muscle regeneration.

2.7. Statistical Analysis

Statistical comparisons of all groups within each parameter were examined using single T-test.

3. RESULTS

3.1. In Vitro Study

The tensile strength, burst pressure and total energy consumption to complete the anastomosis were studied. The results are presented in the Fig. 3. There were significant differences in burst pressures between the grafts welded with the PSH stent and those using the liquid solder. Higher burst pressures were observed in the PSH stent group. The most of burst pressures measurements could not be recorded because our pressure recorder was calibrated to a maximum pressure of 200 mmHg. A 83.3% (5/6) of measurements was above 200 mmHg in the PSH stent groups. Only 66.7% (4/6) in liquid solder group was over 200 mmHg. The tensile strength of the PSH stent group were 523.8± 183.7 g/cm^2 . In the liquid solder group, the average of tension was 371.7 ± 197.4 g/cm^2. These values were significantly different ($P<0.05$). The total energy consumption to complete the anastomosis in the both of the PSH stent groups and solder group was significantly different. More energy and time was spent at the anastomosis site using the liquid solder (127.3 ± 45.8 J.) as compared with using the PSH Stent (83.7 ± 37.8 J) for laser welding.

3.2. In Vivo Study

The table 1 compares the welding time and propensity to leakage during the acute experiments. Welding time for ureter to heterograft anastomosis was significantly ($P<0.05$) decreased in the PSH stent group (67.1 ± 26.5 sec.) compared to the albumin solder group (121.3 ± 38.2 sec.). Leakage at the anastomotic sites was interrogated using retrograde ureterography. There was no immediate leakage in both groups. In the chronic studies, radiological examination revealed varying degrees of stricture and hydroureteronephrosis in both groups (Fig. 4). However, The renal function still remained. The gross and histological examination showed that a solid construct remained the gap of ureters after 3 hours postoperatively at the PSH stent laser welding. A sponge construction was observed at liquid solder laser welding. At 2 weeks postoperatively, the albumin of the PSH stent plug was degraded and penetrated by fibroblasts and urothelia migrated on the welding surface (Fig 5). By 4 weeks, the albumin was degraded.

4. DISCUSSION

Laser tissue welding has been used in a number of studies in the genitourinary tract. These studies included repair of the vas deferens, ureter, bladder and urethra (2,5-7). This technology has interested urologists because it possesses many advantages compared to conventional techniques. The conventional methods such as suturing, stapling and gluing might cause a foreign body reaction, lithogenesis and leakage. Since the advent of laser soldering in 1986 (8), the strength and reliability of laser welding has been promising. Human albumin solder is being widely used for laser welding due to its complete immunological biocompatibility (9). However, the mechanism of laser welding is still not completely understood. A fashionable explanation is that there is thermal remodeling of tissue proteins, interdigitation of collagen fibrils, and formation of biological glue from the cross-linking of collagen. The cross-linking process is considered to be by noncovalent bonding (10). Some interesting results are that increasing solder concentration will enhance laser-welding strength (3,9). This phenomena can be explained as 1) a higher concentration of solder means a greater quantity of albumin molecules (per ml of solder) for binding with tissue and for the creation of the durable biological plug 2) a higher concentration of solder may require less desiccation of water from the solder, which means decrease air bubble formation as the solvent “boils” off. The air bubbles formed sponge stricture may lead to decrease tensile strength. Our histology results demonstrated that the sponge like coagulum formed with 50% albumin liquid solder and a solid homogenous albumin mushroom like plug formation was observed with the PSH stent coagulation.

Other problems of laser welding are difficult to handle with an ideal welding endpoint. At current studies, as makers of endpoint of laser welding depended on the surgeon's experience that is to look for visible signs of the tissue or solder being denatured, such as discoloration. This is a very rough and unreliable marker. It might result in unreliable laser soldering. The failure of the laser solder welding may be due to a detachment of interface between tissue and solder or rupture of solder matrix. It might be caused by: 1) "under-cooked" or under-coagulation due to solder denatured incompletely, 2) "over-cooked" to deconstruct solder-tissue non-covalent bond (10). So, it is important to obtain an appropriate energy output during the laser solder procedure. In our study, the PSH stent was designed as ureteral intraluminal support and provided for a precise end to end rigid ureteral apposition. The laser energy irradiated through the tissue to interface between the tissue and the stent so that minimized the energy consumption. This is an easy, reproducible and reliable technique for ureteral laser anastomosis. It provides burst strengths in excess of 180 mmHg, thus giving a high welding strength that requires less energy usage than the conventional liquid solder welding. However, In the chronic study, there were varying degree ureteral stricture and hydronephrosis in both groups.

With the results of these experiments, the PSH stent act as a solid solder and intraluminal stent to enhance welding strength and support a precision apposite for tubular organ welding. Further studies for decreasing tissue thermal damage are performing.

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