Testing of a new prototype surgical stapler that automates the rollover sleeve technique for venous anastomoses

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ABSTRACT

The creation of successful vascular anastomoses is of primary importance in many surgical fields. Numerous attempts to automate this process have been made. These techniques have slowly gained acceptance, but their use is still limited. This report details feasibility testing of a new prototype stapler that automates the rollover sleeve technique for venous vascular anastomoses.

Male and female mongrel dogs (n=7) (25-32 kg) were used. A segment of the right (n=5) or left (n=2) iliac vein was harvested for interposition grafts after the contra lateral side was transected. In each dog, two end-to-end venous anastomoses at the interposition grafts were performed. The *standard anastomosis* employed continuous mattress sutures. The *experimental anastomosis* was performed with a new prototype surgical stapler. The stapled anastomosis was proximal and the sutured was distal. In all experiments, it was possible to perform the experimental anastomosis with the stapler. Complications included two small leaks, one due to misfiring of a single pin in one experimental site. These leaks required suture reinforcement. One dog died of hemorrhage due to a slipped suture at the vein harvest site. One vein had thrombus seen at the sutured site although no technical abnormalities at either of the anastomoses could be found. After two weeks, grafts were inspected grossly and histologically. Healing appeared normal. There was a trend for less inflammatory cells infiltrating stapled sites; however, this was not statistically significant. The experiments demonstrate that this device can automate the rollover sleeve technique for venous anastomoses.

Key terms: Automated stapler prototype testing, end-to-end venous anastomosis, rollover sleeve technique, surgical staplers, vascular anastomoses,

PROLOGUE

No one who writes a statement in this volume will convey the essence and spirit of Eduardo Rojas. Perhaps if you, the reader, are imaginative and read between the lines, you may catch a glimpse of him. If so, you are lucky.

My husband (AGT) and I (PBC) have known Eduardo Rojas for almost 20 years. I first met "Guayo" during an NIH interview. I think he introduced himself as Eduardo Emilio Rojas. The words flowed off his tongue like music. Charming is a word that easily comes to mind. He never used "doctor", "professor" or any other professional title, although he possessed

many. He was simple and understated. I was interviewing for a position as a fellow with his wife, Illani Atwater. Eduardo explained that he would gladly show me the lab until Dr. Atwater returned. Once I said yes, he launched himself into biophysics in general and islet physiology in particular. He spoke with such passion, energy and detailed knowledge that it left no doubt that Dr. Atwater was clearly onto something. There was no question that this lab at NIH was *the* place to be. When I was offered the position, I excitedly accepted.

Eduardo Rojas is a doctor, professor, inventor, writer, teacher, lecturer, discoverer, pioneer and friend. I wish this journal could feature a holographic moving

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Received: July 27, 2005. Accepted: August 31, 2005

and speaking Eduardo on the cover. If such a thing could be conjured, he would be smiling. It would surely show him in action since Eduardo seldom rested or slept. He was always working, even in his sleep. But he would listen before he would talk. He is competitive. He finishes projects. He does not quit. Whatever he does, he works through it like a training champion. He is an ideal blend of mind and heart. He loves everything that illuminates the human condition. He was always teaching even when at rest. He still is. He adopted (officially and unofficially) everyone he cared about. He always tried to get people to reach goals that they did not believe they were capable of achieving. Mostly he succeeded. He was an intellectual giant. Curiously enough he is also an eccentric, artsy and sporty sort of mad professor type, who loves Chile, soccer, dancing, music, children, wives, families and all modern technology. He was completely in his element when surrounded by clicking and whirring machines, mostly built by him. He is a wonderful, adventurous, eclectic Renaissance man. He still takes risks, learns new things and new skills despite the curves that life has thrown him. He continues to put up with us all.

(Editor's note: Eduardo Rojas knew about the stapler and encouraged the authors to pursue the idea. He thought it would work.)

INTRODUCTION

Successful vascular anastomosis is vital, particularly in the fields of vascular, cardiothoracic and transplantation surgery. Efforts to automate this process have been made for well over 50 years (Von Petz, 1924; Androssov, 1956; Kahn et al., 1965; Cooper et al., 1967; Bertelsen & Rygg, 1967; Ravitch & Steichen, 1982a). Thus, the search for the "ideal" method(s) to automate making anastomoses is neither new nor has it been abandoned. The evolution of this field, over time, has led to the introduction of new waves of staplers bearing only slight resemblance to their ancestors (Ravitch & Steichen, 1982b; Oka

et al., 1982). In addition, technologies such as clips, couplers glues and welding materials have been, and continue to be developed to facilitate joining hollow viscera (Leppaniemi et al., 1996; Werker & Kon, 1997; Haruguchi et al., 1998; Geevarghese et al., 1999).

Many of these techniques have gradually gained acceptance over time. They have proven useful, saved time and are safe. Nevertheless, use of these devices and techniques by the broader market of potential users has been limited to very specific applications in parts of surgical procedures (Alfrey et al., 1990; McEntee & Nagorney, 1991; Cohen, 1992; Steichen et al., 1992; Kirsch et al., 1992; Friedman et al., 1994; Ramacciato et al., 1996; Holzinger et al., 1996; Mital et al., 1996; Nataf et al., 1997; Imai et al., 1999; Hartung et al., 2004; Kaneko et al., 2004). Their infrequent application in spite of the obvious demand has been due in part to their complexity, bulkiness, lack of user friendliness, and the need for specialized training in the use of these techniques. In addition, there are more standard and serious problems such as device failure, infection, stenosis, and thrombosis at the anastomotic site (Chegini et al., 1988; McCarty & Gedroyc, 1993; Yim & Ho, 1995). Hence, the gold standard for joining two vessels remains the tried and trusted hand-sutured anastomosis. The increasing use of minimally invasive surgical techniques results in an increased demand for the adaptation of currently used surgical staplers and the development of new ones for use in endoscopically performed procedures (Chan et al., 2000; Castronuovo et al., 2000; Alimi, 2004; Smith et al., 2005). A useful technique called the rollover sleeve technique (Tzakis & Stieber, 1990) has been extensively used in performing manually sutured end-to-end and end-to-side venous anastomoses. It can also be used for arterial procedures. The advantage of the rollover sleeve technique is that it routinely provides intimal approximation and avoids adventitial interposition at the anastomotic line. These two factors are both thought to be critical for avoiding late complications of thrombosis and stenosis at the suture line. The performance of the rollover sleeve technique

has not been automated with any currently used stapling device.

We report, herein, the results of preliminary testing of a prototype stapler specifically designed to automatically perform vascular anastomoses using the rollover sleeve technique.

METHODS

Animal studies

Male and female mongrel dogs (n=7) weight: 25-32 kg were used for the study. The University of Miami Animal Care and Use Committee approved the study protocol.

A schematic drawing of the stapling device and its use in these experiments is shown in Figure 1. In brief, the stapler consists of a brass nut surrounded by a locking brass stockade. This is locked over the two vessel segments to be joined by a plastic overlay consisting of stainless steel lock rods and a wheel containing the staples. The staples are fired by a pullstring mechanism.

Figure 1A is a diagram of the disassembled device drawn approximately to scale. The brass nut and surrounding stockade are shown in the lower section of Figure 1A and the locking plastic overlay containing the staples, lock rods, and pull strings is shown in the upper part of Figure 1A.

Figure 1. **A:** Illustrates a disassembled device drawn to scale (inches). **B:** Shows how the rollover sleeve technique is applied with the device. The approaching vessel (below) is brought up and over the rolled over segment already in place on the stockade nut. Next, the two segments would be secured in place by locking the plastic overlay that contains the staples (shown at top of A). The pull strings fire the staples (**C**). **D:** Illustrates how the staples secure the anastomosis. The walls of the approaching vessel and the rolled over segment are joined by the staples with the major advantage that the endothelial surface is not affected.

Figure 1B indicates how the rollover sleeve technique is used with the device. The approaching vessel segment (below) to be joined to the already rolled-over segment on the nut of the brass stockade (above) are both illustrated.

In a procedure, the device would be used as shown in figure 1C. After locking the segments of vessel to be joined on the device, the surgeon pulls the strings that fire all the pins with this single motion. The surgeon unlocks the device and the anastomosis would be completed.

Figure 1D indicates how the staples secure the rolled-over segments. The walls of the approaching vessel and the rolled-over segment are joined by the staples with the major advantage that the endothelial surface is not affected. The mechanics of the stapling device makes it possible to keep the two segments very secure within the device so that when the segments fall back into place, no part of the staple shows on the endothelial surface. The staples by design compress the walls of the vein between two flat surfaces and prevent exposure of the pin material to the blood stream. In theory, there should be no exposure of foreign body to the blood stream.

Surgical procedure

Sutured anastomoses were performed by hand with continuous mattress sutures using the rollover sleeve technique (Tzakis & Stieber 1990). The hand-sewn anastomoses were done with Prolene® 6-0 blue monofilament suture, BV-1 needle, 3/8 circle taper point (Ethicon, Somerville, New Jersey).

The stapled anastomoses were accomplished with the patented ZakPak™ (Zakease Surgical, Inc., Miami, Florida) disposable surgical stapler as follows. In step one, a segment of vein to be anastomosed as an interposition graft was placed over the brass collar on the device and rolled over.

The rolled-over position was held with two vertical stay sutures. Next, the segment to which this would be joined was pulled over this first segment and locked in place.

Once the device was locked together, the entire anastomosis could be accomplished in a single maneuver. The staple pins (n=8) were fired using a pull string on the device (Fig. 1).

Pathology studies

After two weeks, the interposition grafts were inspected visually and examined grossly. After assessing patency, the tissue specimens that contained both the sutured and stapled sites were excised and fixed in 10% buffered formalin. In four cases, longitudinal sections were made through the anastomotic vein segments. Two specimens were sectioned transversely. All tissue samples were embedded in paraffin, cut at 5 microns, and stained with hematoxylin and eosin as well as with Masson's trichrome stain.

The following parameters were assessed for each sample using a semiquantitative scoring system, detailed below:

A. Presence or absence of attached fibrin and/or thrombus partially occluding the vessel wall:

Score:

0. No evidence of fibrin or thrombi.
1. Fibrin strands present attached to the intima.
2. Presence of thrombi occluding less than 5% of the lumina.
3. Presence of thrombi occluding > 10% of the lumina.

B. Degree of vascular medial injury:

Score:

1. No evidence of medial injury.
 2. Mild disruption of the smooth muscle layer with focal replacement by granulation and fibrous tissue.
 3. Moderate disruption of the smooth muscle layer with focal replacement by granulation and fibrous tissue.
- Severe disruption of the smooth muscle layer with extensive replacement by granulation and fibrous tissue.

C. Degree of acute and chronic inflammation and foreign body granulomatous reaction:

Score:

0. No evidence of inflammation or reaction.
1. Mild focal inflammation.
2. Moderate inflammation that expands the medial layer.
3. Severe inflammation with adventitial extension and fat necrosis.

RESULTS

In all cases, the experimental anastomosis was successfully completed with the prototype device (Table 1). In 5/7 experiments, the device performed the anastomosis flawlessly. Figure 2 shows a representative photograph of the moment of perfusion of the two anastomotic segments in the dog experiments. The sutured anastomosis is shown at the top left, and the stapled one is shown in the lower right of the photograph. There were no leaks when the vessels were perfused. Complications (Table 1): In one stapled anastomosis, a small leak was noted after perfusing the graft. This leak was easily visible after perfusion and was due to misfiring of one pin. The leaking vessel required a single suture to assure a complete seal. There was one post perfusion leak that was not

explained by misfiring of any of the pins. This also was seen easily at perfusion and fixed with a suture. One dog died of hemorrhage on the second postoperative day. *This was due to a slipped suture at the vein-harvesting site.* There were no problems with the anastomoses noted at necropsy in this animal; however, the graft sites were not analyzed histologically in this animal. (Data were not comparable in time). There was venous thrombosis in one animal noted at the manual suture site, although when the grafts were inspected there were no technical problems evident (Table 1).

Figure 3 shows a representative gross specimen presenting the sutured anastomosis in panel A to the left and the stapled anastomosis in the same dog in panel B on the right. On gross inspection of all the grafts, the endothelial surface of the sutured anastomoses showed some Prolene[®] exposed. No foreign body penetration was evident on the endothelial surface of any of the stapled anastomoses. All grafts showed normal healing at both sites. There was a trend for less inflammatory cells infiltrating the stapled sites; however, this finding was not statistically significant ($p=0.06$ one-tailed and $p=0.13$ two-tailed Student's *t*-test) (Table 2). In fact, there were no significant differences in the histologic appearance or in any of the analyzed parameters of injury or inflammation in the stapled anastomoses when compared with controls (Table 2).

TABLE 1

Results of Stapler Test for venous interposition grafts in dogs

Animal	Vein harvest side	Stapler Complications	Gross pathology
1	Left	One misfired pin. Leak required 1 suture.	Patent at 15 days.
2	Left	None	Thrombus at sutured site 15 days.
3	Left	None	Patent at 14 days.
4	Left	None	Patent at 15 days.
5	Right	None	Patent at 14 days.
6	Right	None	Tie slipped at vein harvest site. Animal died 2 nd day.
7	Left	None, post-perfusion leak required one suture.	Patent at 14 days.

Figure 2: Photograph of a representative experiment. The moment of perfusion of the anastomoses is shown. The sutured anastomosis is shown at the top left. The stapled anastomosis is evident to the left of the two surgeons' gloved fingers. No leaks are present.

Figure 3: Representative gross specimen. A (left) shows the endothelial surface of the sutured anastomosis, and B (right) shows the endothelial surface of the stapled anastomosis in the same animal.

TABLE 2

Semiquantitative inflammation/injury scores of stapled and sutured venous interposition grafts in dogs

Exp.	Condition	Fib./Thromb. Score	Medial Injury Score	Inflammation Score
1	Sutured	0	3	3
1	Stapled	0	3	3
2	Sutured	3	3	3
2	Stapled	3	3	2
3	Sutured	0	2	2
3	Stapled	2	2	1
4	Sutured	2	2	2
4	Stapled	1	2	1
5	Sutured	1	2	2
5	Stapled	0	2	2
6	Sutured	0	3	2
6	Stapled	0	3	2
Mean $\pm$ SEM	Sutured	1.2 $\pm$ 0.58	2.4 $\pm$ 0.25	2.2 $\pm$ 0.2
Mean $\pm$ SEM	Stapled	1.2 $\pm$ 0.58	2.4 $\pm$ 0.25	1.6 $\pm$ 0.245

(No significant differences: $p > 0.1$ for all analyses by paired two-tailed Student's t-tests)

DISCUSSION

These are the first data detailing testing of this prototype surgical stapler in actual surgeries to perform vascular anastomoses in animals. The anastomoses were accomplished successfully with the stapler in all 7 experiments. There were no infections. The one mortality related to a slipped tie at a vein harvest site rather than a stapler complication. We noted in the gross specimens that in every case, Prolene® could be seen on the endothelial surface; however, no foreign body could be seen on the endothelial surface of the stapled specimens. In fact, the one thrombosis that occurred was located on a sutured anastomosis, although there were no visible technical imperfections. We believe this was a chance occurrence. The quantitative data support the notion that *the healing of stapled anastomoses with the ZakPak™ is at least as good as sutures, the current gold standard*. Indeed, the device mechanics allow for the apposed ends to be secured more tightly. This advantage combined with the interaction with staple mechanics, allows for an apparent non-

penetrating apposition. These taken together allow for less exposure of foreign body material on the endothelial surface. The analysis of the histology specimens shows a trend for less endothelial reactivity with the stapler. It remains to be seen if less vascular reactivity as seen histologically would result in a lower incidence of thrombosis in stapled anastomoses.

Complications related to the use of the stapler included one incomplete firing of one of the eight staples. This complication resulted in an immediate anastomotic leak that was obvious and easily corrected. In addition, one anastomosis had a leak after reperfusion, but no staple problem could be identified. Again, this was immediately evident and easily corrected. These preliminary results clearly demonstrate the feasibility of automating the rollover sleeve technique with this device or one like it. Nevertheless, some changes in design will be made to correct problems noted in the experiments. The most significant changes will be targeted to minimize the possibility of incomplete staple firing and leaks. The actual use of the prototype in surgical procedures, rather than in simply linking up

tubes or vessels on the bench, indicated that other desirable design modifications could make the device faster and easier to use in more complex surgical procedures. The data are encouraging and provide evidence that this device should be further modified and tested. The firing mechanism is simple. The stapler is convenient. It is made to be fully disposable. As a result of using the device in experimental surgeries in these preliminary tests, planned modifications include making the device smaller with a handle to extend the reach of the surgeon to difficult places. A faster and simpler way to hold the rolled over sleeve position than the stay sutures will be added.

Some changes in design will be made to insure complete and easy firing and less space between staples. This should prevent leaks that were seen in these experiments. Once the alterations are completed and tested for quality control, the modified device will be used for *ex vivo* experiments linking tubes and vessels. The intention would be to follow these tests with timed experiments of the use of the device to perform venous anastomoses in animals. The final goal would be to have a device that can be used to successfully perform venous anastomoses in complex surgical procedures in humans.

ACKNOWLEDGEMENTS

Supported in part, by an unrestricted grant from: Med Immune, Inc, Gaithersburg, MD 20878, and USA.

The ZakPak™ surgical stapler is a patented medical device owned by ZakEase Surgical, Inc. This is an ongoing project developed while Drs. Tzakis and Carroll were in Pittsburgh, Pennsylvania, USA. The patents are held by Dr. Tzakis who is the inventor of the stapler. Dr. Carroll established ZakEase Surgical Inc., and is President.

The authors gratefully acknowledge the secretarial assistance of Ms. Jennie Benson in the preparation of the manuscript. The drawings were done by Dr. Evangelos Misiakos.

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