

Animal model to compare the effects of suture technique on cross-sectional compliance on end-to-side anastomoses[☆]

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Abstract

Objective: An animal model has been developed to compare the effects of suture technique on the luminal dimensions and compliance of end-to-side vascular anastomoses. **Methods:** Carotid and internal mammalian arteries (IMAs) were exposed in three pigs (90 kg). IMAs were sectioned distally to perform end-to-side anastomoses on carotid arteries. One anastomosis was performed with 7/0 polypropylene running suture. The other was performed with the automated suture delivery device (Perclose/Abbott Labs Inc.) that makes a 7/0 polypropylene interrupted suture. Four piezoelectric crystals were sutured on toe, heel and both lateral sides of each anastomosis to measure anastomotic axes. Anastomotic cross-sectional area (CSAA) was calculated with: $CSAA = \pi \times mM/4$ where m and M are the minor and major axes of the elliptical anastomosis. Cross-sectional anastomotic compliance (CSAC) was calculated as $CSAC = \Delta CSAA/\Delta P$ where ΔP is the mean pulse pressure and $\Delta CSAA$ is the mean CSAA during cardiac cycle. **Results:** We collected a total of 1 200 000 pressure-length data per animal. For running suture we had a mean systolic CSAA of $26.94 \pm 0.4 \text{ mm}^2$ and a mean CSAA in diastole of $26.30 \pm 0.5 \text{ mm}^2$ (mean $\Delta CSAA$ was 0.64 mm^2). CSAC for running suture was $4.5 \times 10^{-6} \text{ m}^2/\text{kPa}$. For interrupted suture we had a mean CSAA in systole of $21.98 \pm 0.2 \text{ mm}^2$ and a mean CSAA in diastole of $17.38 \pm 0.3 \text{ mm}^2$ (mean $\Delta CSAA$ was $4.6 \pm 0.1 \text{ mm}^2$). CSAC for interrupted suture was $11 \times 10^{-6} \text{ m}^2/\text{kPa}$. **Conclusions:** This model, even with some limitations, can be a reliable source of information improving the outcome of vascular anastomoses. The study demonstrates that suture technique has a substantial effect on cross-sectional anastomotic compliance of end-to-side anastomoses. Interrupted suture may maximise the anastomotic lumen and provides a considerably higher CSAC than continuous suture, that reduces flow turbulence, shear stress and intimal hyperplasia. The Heartflo™ anastomosis device is a reliable instrument that facilitates performance of interrupted suture anastomoses. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Vascular anastomosis; Arterial compliance; Piezoelectric crystals

1. Introduction

Running versus interrupted suture can be reasonably considered one of the most frequent subject of discussion since vascular surgery moved its first steps. To date, this is still an open issue despite many scientific works have been published all over the world. The suture material selected and the suture technique employed can influence the size and the distensibility of the anastomotic lumen [1]. Cross-sectional compliance in the perianastomotic zone, wall shear stress, axial stress, and their relationship with intimal hyperplasia are the most frequently considered parameters to compare the two different techniques [1,2]. If we try to resume the pros and cons of each technique we conclude

that running suture is faster and somehow easier to do but it can produce a purstring effect that can impair the hemodynamic performance of the anastomosis. Multiple stitch technique avoids purstring effect but requires more time and is often characterized with bleeding from the suture line.

The development of a surgical device that allows performance of a multiple stitch coronary sutures in an easier and faster way than usual, and the possibility to calculate the cross-sectional anastomotic area during each phase of the cardiac cycle using a brand new technology based on piezoelectric crystals, led us to develop an animal model to compare the effects of suture technique on luminal dimensions and compliance of end-to-side anastomoses.

2. Methods

Instrumentation: length measurements were obtained with small piezoelectric crystals that transmit and receive

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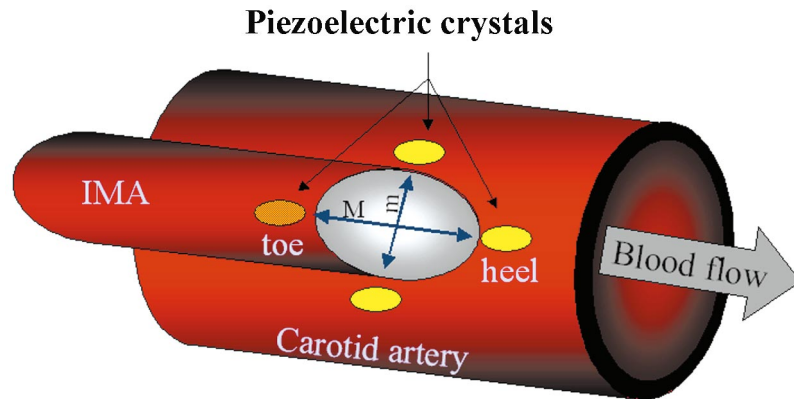


Fig. 1. Representation of end-to-side anastomosis between IMA and carotid artery. In yellow piezoelectric crystals that have been placed on toe, heel and lateral side of the anastomosis.

short ultrasonic pulses. The crystals were sutured on toe, heel and both lateral sides of each anastomosis to measure distances as shown in Fig. 1. Under electric stimulation a crystal produces a sound wave that is detected by a second crystal, inducing an electrical response. A simple calculation ($\text{Distance} = \text{Velocity} \times \text{Time}$) yields the distance between the crystals. Sound velocity in pig's heparinized blood at 38°C is 1.04 mm/ μs [3]. The system setting is as follows: sampling rate 457 Hz; transmit pulse 357 m/s; sampling time 5 s. Extensive description of the device and validation of the technique have been reported previously [4].

Arterial pressure was obtained using high fidelity pressure probe (Millar Mikro-Tip, model MPC-500) with a pressure range of -50 to 300 mmHg and a sensitivity of 5 $\mu\text{V/V}$ per mmHg.

The Heartflo™ anastomosis device (Perclose/Abbott Labs, Inc.) was used to perform the end-to-side anastomosis with interrupted suture technique. It consists of a hydraulically activated delivery mechanism, and two branches, with each branch housing needles and the opposite ends of ten 7-

0 polypropylene sutures. The device first simultaneously delivers ten sutures of one branch through the wall of the vessel (coronary), and then through the wall of the graft. The surgeon completes the anastomosis using conventional surgical knot tying techniques (Fig. 2).

The experiment was performed on three domestic pigs, 90 kg in weight. All animals received human care in compliance with the European Convention on Animal Care and the study has been approved by our ethics committee.

Surgical technique: pigs were given Ketamine 15 mg/kg, Azaperon 0.5 mg, Atropine 2 mg. General anaesthesia was induced and maintained with Fluotane 1.5%. EKG, SatO₂ and pCO₂ were continuously monitored. Pigs lay on the back with a neck extension of 160°. Both carotid arteries were exposed. The pressure probe was inserted in the left common femoral artery and pushed up to the aortic arch. After median sternotomy, both internal mammalian arteries (IMAs) were isolated and 9000 U of Heparin were injected. IMAs were sectioned distally and rotate of 180° to perform an end-to-side anastomoses on carotid arteries. The carotid arteriotomy was performed with the Heartflo™ scissors that

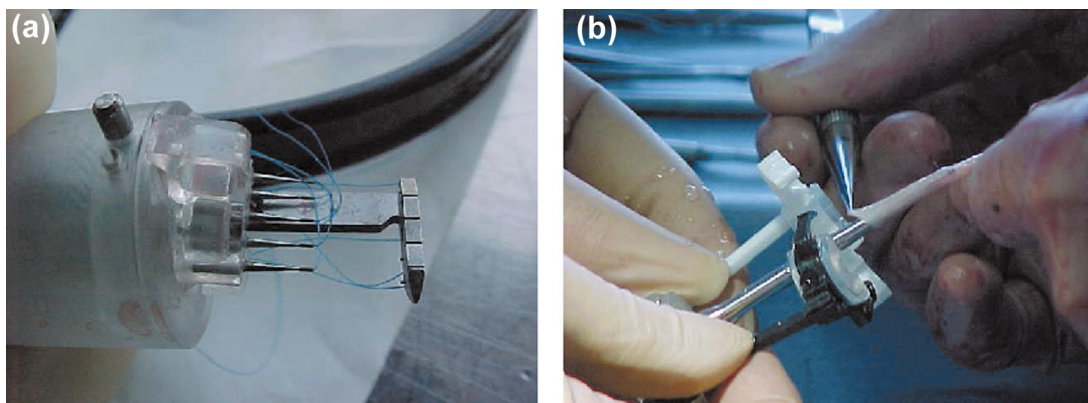


Fig. 2. The Heartflo™ anastomosis device (Perclose/Abbott Labs, Inc.) was used to perform the end-to-side anastomosis with interrupted suture technique. It consists of a hydraulically activated delivery mechanism, and two branches, with each branch housing needles and the opposite ends of ten 7-0 polypropylene sutures. The device first simultaneously delivers ten sutures of one branch through the wall of the coronary vessel (a), and then through the wall of the graft (b). The surgeon completes the anastomosis using conventional surgical knot tying techniques.

makes the correct arteriotomy length in which the device perfectly fits. One anastomosis was performed with 7-0 polypropylene running suture. The other was performed with the Heartflo™ anastomosis device. Four piezoelectric crystals were sutured on the carotid artery at toe, heel and sides of each anastomosis to measure major and minor anastomotic axes (Fig. 1). Carotid arteries were clamped proximally to the anastomosis. Finally, pressure probe, EKG and crystals were connected to our measurement system. Artery was irrigated with NaCl 0.9% solution at 37° every 10 min to prevent desiccation and to control its temperature. During data acquisition we carefully avoided any manipulation of the animal. In animal No. 3 blood flow in both carotid arteries was assessed with a high fidelity flowmeter probe (Medi-Stim perivascular flowmeter probes, size 4 mm with flow relative accuracy of 1%, resolution of 1 ml/min, flow sample rates 333 Hz).

Data collection: both carotid arteries were clamped 2 cm proximally to the anastomoses and after 15 min of stabilisation, data collection was carried out for a period of 5 s without interruption at least four times per minute for 1 h for each animal. During every second of acquisition anastomotic diameters of both types of sutures and blood pressure were captured 457 times.

To avoid blood mass and pulse waves interference we switched the transmitter and receiver functions of the piezoelectric crystals.

Anastomotic cross-sectional area was calculated assuming that the shape of the anastomosis corresponds to a regular ellipse and distances between crystals corresponds to major and minor axes of the considered ellipse (Fig. 1). If those hypotheses are accepted Cross-Sectional anastomotic area (CSAA) can be calculated as:

$$CSAA = \pi \frac{mM}{4}$$

where m and M are the minor and major axes of the anastomosis. CSAA is expressed in mm². Cross-sectional anastomotic compliance (CSAC) was calculated as the ratio between variations in anastomotic cross-sectional area ($\Delta CSAA$) and blood pressure (ΔP):

$$CSAC = \frac{\Delta CSAA}{\Delta P}$$

Table 1
Mean cross-sectional anastomotic area^a

| Animal | Running suture | | | Interrupted suture | | |
|-----------|----------------|-------------|-----------------|--------------------|-------------|-----------------|
| | Diastole | Systole | % $\Delta CSAA$ | Diastole | Systole | % $\Delta CSAA$ |
| 1 | 25.68 ± 0.2 | 26.38 ± 0.2 | 2.7 | 17.23 ± 0.1 | 21.71 ± 0.2 | 20.6 |
| 2 | 27.12 ± 0.3 | 27.67 ± 0.2 | 2 | 17.04 ± 0.2 | 21.89 ± 0.1 | 22.1 |
| 3 | 26.11 ± 0.3 | 26.79 ± 0.3 | 2.6 | 17.87 ± 0.2 | 22.34 ± 0.2 | 20 |
| Mean ± SD | 26.30 ± 0.5 | 26.94 ± 0.4 | 2.4 | 17.38 ± 0.3 | 21.98 ± 0.2 | 20.9 |

^a Mean cross-sectional anastomotic area (CSAA) (mm²) ± standard deviation, in systole and diastole for running and interrupted end-to-side anastomoses calculated assuming anastomosis being a regular ellipse in shape.

CSAC is expressed in m²/kPa.

Data are presented as mean ± standard deviation (SD)

3. Results

We collected a total of 6×10^5 simultaneous data for blood pressure, and anastomotic axes for both anastomosis, per animal. For running suture we had a mean systolic CSAA of $26.94 \pm 0.4 \text{ mm}^2$ and a mean CSAA in diastole of $26.30 \pm 0.5 \text{ mm}^2$ (mean $\Delta CSAA$ was $0.64 \pm 0.0 \text{ mm}^2$ that correspond to 2.4% incrementation of diastolic area during systole). CSAC for running suture was $4.5 \times 10^{-6} \text{ m}^2/\text{kPa}$. For interrupted suture we had a mean CSAA in systole of $21.98 \pm 0.2 \text{ mm}^2$ and a mean CSAA in diastole of $17.38 \pm 0.3 \text{ mm}^2$ (mean $\Delta CSAA$ was $4.6 \pm 0.1 \text{ mm}^2$ that correspond to 20.9% incrementation of diastolic area during systole). CSAC for interrupted suture was $11 \times 10^{-6} \text{ m}^2/\text{kPa}$. Table 1 reports anastomotic CSAA values in systole and diastole for both sutures.

Mean diastolic pressure was $60 \pm 13.2 \text{ mmHg}$; mean systolic pressure was $99 \pm 12.8 \text{ mmHg}$; pulse pressure was between 20 and 46 mmHg (mean $32 \pm 8 \text{ mmHg}$) and the mean heart rate was $88/\text{min} \pm 18$.

Blood flow in carotid was $54 \pm 12 \text{ ml/min}$ for interrupted suture, and $62 \pm 13 \text{ ml/min}$ for running suture.

IMAs had a mean diameter of $3 \pm 0.2 \text{ mm}$. Carotid arteries had a mean diameter of $5.2 \pm 0.2 \text{ mm}$.

The mean time to perform the interrupted suture was $10 \pm 2 \text{ min}$. The mean time to perform the continuous suture was $7 \pm 1 \text{ min}$.

4. Discussion

This study demonstrates that suture technique has a substantial effect on CSAC of end-to-side anastomoses. Interrupted suture provides a CSAC considerably higher than continuous suture and can be reasonably considered the most ‘physiologic’ suture because it keeps the biomechanical properties of arterial wall as close as possible to those of native vessel [2]. This anastomotic behavior appears to result mainly from the elastic recoil of the arterial wall constituents that is better preserved with interrupted suture [5]. Therefore, the notion that difference in hemody-

dynamic property of end-to-side anastomoses done with the two considered techniques are negligible [1], deserves reappraisal.

Furthermore, it is clear from the data provided in the study that systolic increase of cross-sectional anastomotic area (CSAA) is definitely bigger if interrupted suture is used and this behavior may theoretically improve the systolic flow through the anastomosis.

The limitations of the study resides in the fact that the model represents a situation that doesn't exist in surgical practice. It should reproduce the hemodynamic condition of end-to-side anastomosis between IMA and Left Anterior Descending coronary artery, but carotid and coronary artery have a different histological pattern. Actually, muscular layer is much more represented in carotid than in coronary arteries.

The surgical procedure may also have modified the genuine elastic properties of the vessel wall. However, careful attention was paid not to severe the adventitia in the proximity of the sutures, and in the translation of IMAs to avoid kinking and twisting.

Another limitation of the model is that we assume the anastomosis has a perfect elliptic shape and that distances we calculate with piezoelectric crystals correspond to the maximal and minimal diameters of this ellipse. Although other authors have done this assumption before [1,5] we are doing histological morphometric studies on end-to-side anastomoses performed with Heartflo™ device to verify their geometry.

The reference method for arterial diameter and cross-sectional compliance determination is the non-invasive ultrasound (NIUS 02) [6]. But, if we consider that end-to-side anastomosis doesn't lie on one cross-sectional plan we can assume that A-mode echotracking system is not a reliable method to calculate CSAC. Baumgartner proposes to measure anastomosis axes on the radiographs after anastomosis is removed, but it seems to be the less accurate method [1]. We chose sonometric technology to calculate CSAA and CSAC. Piezoelectric crystals have the highest resolution (15 μm) [4] and are easy to handle. This technique has been extensively used in vascular surgery mostly to validate Intra Vascular Ultra Sound measurements [3,4].

In Fig. 3 is plotted the correlation between pulse pressure and CSAA for interrupted and continuous sutures. The two parameters are directly correlated only if interrupted suture technique is used ($R_{\text{interrupt}} = 0.94$ vs. $R_{\text{running}} = 0.56$). The CSAA increase during systole causes a reduction of vascular resistance and this can improve the blood flow through the anastomosis as hypothesised the first time in 1960 by Szilagyi [7]. However, when we measured the flow through the anastomosis we did not find any difference in systolic outflow between the two techniques and this is probably due to the sensibility of the flowmeter probe.

CSAA was slightly smaller for interrupted suture probably because we used a dedicate Pot's scissors for the arteriotomy so that the device can perfectly fit in the arteriotomy.

Better anastomotic compliance means less suture-line stresses [8,9], reduces flow disturbances and may reduce the disposition toward the development of intimal hyperplasia or thrombosis [5,10]. Computer flowdynamic simulation demonstrates that a more compliant anastomosis is associated with a less stagnation point due to flow separation (typically on heel, toe and the hood of the graft) giving rise to low wall shear stress that is associated with intimal hyperplasia [11].

Despite 51 patented ideas describing vascular anastomotic devices, and the growing need for them in minimally invasive coronary bypass procedures, no data have been published concerning their clinical evaluation. In an elegant study, Scheltes and colleagues evaluate 11 most attractive end-to-side anastomotic devices and conclude that, in a coronary anastomotic device, the concept of using an anvil for the application of micromechanical bonding elements is not attractive, because excessive wall strain is likely to occur [12]. The Heartflo™ anastomosis device does not use bonding elements. This is a surgical instrument that automates the suture delivery process during the anastomosis procedure via the simultaneous delivery of ten standard 7-0 polypropylene suture through the vessel wall. After the deployment of the device, the surgeon manually ties off the ten sutures to complete the anastomosis, similar to a hand-sewn interrupted anastomosis (Fig. 2). No significative bleeding from the suture line has been observed.

The Heartflo™ anastomosis device reduces the time to perform an interrupted end-to-side anastomosis and it should facilitate a consistent and reproducible anastomosis for minimally invasive and beating heart surgery.

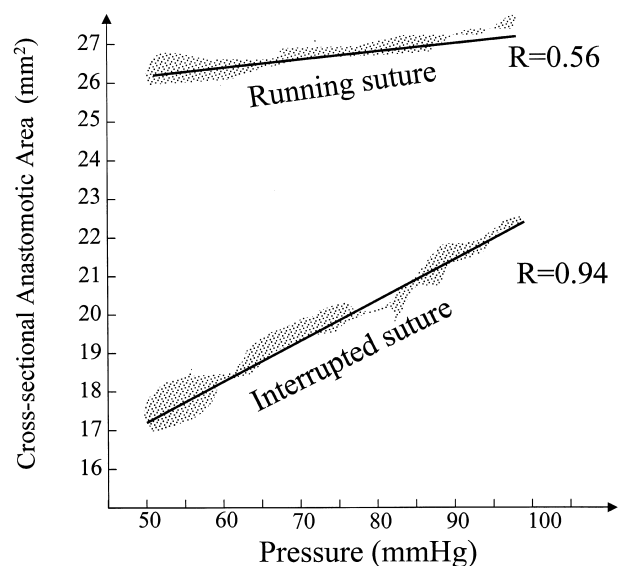


Fig. 3. The correlation between pulse pressure and cross-sectional anastomotic area (CSAA) for running and interrupted sutures are plotted. The two parameters are directly correlated only if interrupted suture technique is used ($R_{\text{interrupt}} = 0.94$ vs. $R_{\text{running}} = 0.56$).

5. Conclusions

We believe this model, even with the limitations described above, can be a reliable source of information improving the outcome of coronary artery bypasses. This study demonstrates that suture technique has a substantial effect on cross-sectional anastomotic compliance of end-to-side anastomoses. Interrupted suture may maximise the anastomotic lumen and provides a considerably higher CSAC than continuous suture, that reduces flow turbulence, shear stress and intimal hyperplasia. The Heartflo™ anastomosis device is a reliable instrument that facilitates performance of interrupted suture anastomoses.

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