Sutureless coronary anastomoses: revival of old concepts

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Summary
Surgical environment is becoming increasingly challenging for the cardiac surgeon since off-pump coronary arteries bypass grafts and minimally invasive approach came up. The suture technique for coronary anastomosis construction is becoming inadequate to meet new surgeons’ demand. Therefore, there is an increasing need for alternative ways to perform coronary bypasses. This article reviews the most recent devices developed for cardiac surgery (Q-Cab and distal connector from St. Jude Medical, CoreLink from Ethicon, GraftConnector from Jomed Int.), and demonstrates that the new anastomotic technologies are based on concepts expressed by Payr and other authors in the 19th century. We propose to consider three aspects to evaluate a sutureless anastomotic device: the device–vessel wall connection, the graft preparation and the anastomosis’ biomechanical properties. Pins, wall eversion on an anvil and squeezing are the three systems used to anchor the connector to the graft and to the native artery. The graft preparation and anastomotic biomechanics are analysed with respect to the possibility of affecting graft patency rate. Finally, we trace the profile of the ideal anastomotic device: minimal graft manipulation, no limitation in anastomotic timing, no material in the vessel lumen and optimal anastomotic angle and compliance. The evidence of long-term graft patency is fundamental for any anastomotic device to become widely acceptable.

Keywords: Vascular connectors; Sutureless anastomosis; Coronary arteries bypass grafts

1. Introduction
Since the beginning of cardiac surgery, proximal and distal anastomoses for coronary arteries bypass grafts (CABGs) have been done with hand-held sutures basically found on the principles of suture technique described by Alexis Carrel in 1902 [1]. The comfort to surgeons in performing a reliable anastomosis with the suture technique and the excellence of its long term results have led to its adoption as the gold standard. In the last ten years, surgical environment has become increasingly challenging for the cardiac surgeon since off-pump CABG (OPCABG) and minimally invasive approach came up. The key element in performing a precise anastomosis is the placement of sutures between coronary arteries and graft vessels. Any imprecision may lead to anastomosis occlusion or severe flow impairment, reported in 10% of OPCABGs [2]. The hand-sew proximal anastomosis still requires the aortic cross-clamp or side clamp with the risk of cerebral complications. Moreover, it is a matter of fact that surgical dexterity is still a determinant factor for anastomosis outcome. Therefore, surgeons need an alternative way to construct a coronary bypass in order to reduce the technical demand, standardise the quality of the surgical procedure, avoid aortic cross-clamp, reduce the individual surgical dexterity as the determinant factor for anastomosis outcome and possibly, expediting the procedure.

This article reviews the anastomotic devices most recently developed to face latest cardiac surgeon’s needs, focusing on the key issues of mechanical anastomosis and demonstrating that the ‘new anastomotic technologies’ are based on concepts expressed in the 19th century.

2. Historical review
New anastomotic technologies are not as new as they seem to be. In his Nobel lecture in 1912, Carrel affirmed that “Many surgeons had previously to myself performed vascular anastomosis, but the results were far from satisfactory”. He was referring to non-suture techniques to construct a vascular anastomosis that had been described since the end of the 19th century. Those non-suture techniques and the devices for proximal and distal anastomoses that are recently brought to our attention share the same fundamental principles.

In the 1890s, many experimental studies of connecting
blood vessels began using both non-suture and suture techniques. Abbe [3] employed an hour-glass-shaped intraluminal glass prosthesis in 1894. Subsequently, ivory cuffs [4], parafined silver tubes [5] and the shin bone of an ox [6] found their way into and around vessels, but the results were very far from good. In 1900, Payr [7] published a description of his absorbable extraluminal magnesium ring design. The proximal end of the severed vessel was threaded through the ring, everted over its edge, and held in place by a circumferential ligature. The distal end was dilated for insertion of the rigid cuff with its everted vessel. The anastomosis was completed by another circumferential ligature, thereby achieving intima-to-intima apposition. In 1904, Payr [8] presented a new device made of two interlocking magnesium rings. Small pins on one side kept the vessel ends everted. The pins passed through both vessel walls and through the holes in the matching ring before being bent to secure the anastomosis. This device showed close resemblance to the system designed by Henroz [9] in 1826 for bowel anastomosis. Payr’s device results were not comparable to those obtained with Carrel’s suture technique.

Blakemore [10] advanced Payr’s technique using vein-graft-lined rigid vitallium tubes to bridge arterial defects and the World War II allowed clinical trials of both suture and non-suture techniques. In an extensive review of vascular trauma during that war, De Bakey and Simeone stated that there was a slight increase in the number of amputations required following Blakemore’s technique, although it was not statistically significant [11]. Moreover, the non-suture technique was used in cases in which suture repair was not feasible and in which the proportion of critical vessels involved was higher. Interest in non-suture technique waned as reconstructive peripheral vascular surgery began to gain acceptance utilizing suture techniques for vein grafts in atherosclerotic vessels. In 1956, Androsov’s [12] vascular anastomotic staple renewed again the attention on non-suture technique. The metallic staple device united vessels by inserting multiple staples simultaneously and bending them into a B shape, thereby securing the anastomosis. Androsov used this device for experimental and clinical end-to-end arterial repairs and vein grafts. Inokuchi modified this technique for end-to-side anastomoses.

The first internal mammary–coronary artery anastomosis constructed with a mechanical device in published in 1961 by Goetz [14]. The device used was similar to Payr’s rings, with tantalum instead of magnesium. Goetz performed end-to-end IMA on LAD and IMA on circumflex artery anastomoses in 12 dogs and long-term results (four animals after 20 months were still alive) were superior to direct suture methods on beating heart [13].

In 1962, Nakayama [14] developed two identical rings with six spaced holes and pins to repair vessels 1.5–4.0 mm in diameter with virtually 100% patency in experimental model. A very promising absorbable anastomotic coupler device for microanastomoses (vessel diameter from 1 to 2 mm) was presented in 1984. In this device, there was no foreign material present in the vessel lumen, there was a perfect intima-to-intima apposition and it had a patency rate of 96% at 12 months in animals. Unfortunately, there was a mean vessel consumption of 4 mm in length during the eversion over the cuffs that affected its diffusion [15]. In the heat-shrink tubing (1991), the concept of vessel wall eversion was considered again and coupled with a heat-shrinkable tubing to ensure the connection between the edges of the severed vessel [16]. Lasers have been used to repair arteries since 1979 [17]. Even if the anastomosis strength has been improved with the use of albumin solder [18], this technique has some important limitations: thermal injury to the vessel wall can lead to pseudoaneurysm formation and anastomotic failure [19]. Moreover, the acute histology suggests entry of albumin into the arterial lumen [18] and the influence of this on long-term patency has not been determined yet.

Recently, a biologic glue coupled with a catheter system that stabilises the anastomosis during glue injection has been developed to perform a coronary anastomosis in three goats, demonstrating the feasibility of the technique [20].

A chronological resume of sutureless anastomosis devices is reported in Fig. 1. However, virtually all those devices presented several disadvantages: (1) complex and cumbersome instrumentation; (2) rigid foreign body enclosing a dynamic dilating structure and (3) non-flexible technique inapplicable for significant vessel size discrepancies or end-to-side anastomoses. New anastomotic devices should overcome these limitations to become widely acceptable.

3. Devices evaluation

New anastomotic technologies include:

- sutureless devices based on:
  - (a) memory shape metal alloy;
  - (b) biologic [20] or synthetic (cyanoacrylate derivate) glue combined or not combined with metallic scaffold [21];
  - (c) laser welding with or without organic solder [18].

- suture delivery device (Heartflo by Perclose–Abbot) [22] that deploys ten 7-0 polypropylene sutures through the wall of the graft and then through the wall of the native coronary. The surgeon manually ties off the ten sutures to complete the anastomosis. The result is an interrupted end-to-side or side-to-side suture.

- suture material used: nitinol (U-Clip by Coalescent) [23] or stainless steel (VCS by Ethicon) [24,25].

Any vascular reconstruction obtained without using hand sewing or hand-tying knots could be considered as mechanical or sutureless anastomosis. If we accept this definition,
there are 63 fundamental international patents concerning sutureless vascular anastomosis devices, updated till August 2001. Most of them are only ideas, still far from clinical use. The devices that are now available for clinical use are shown in Fig. 2, even if some of them are used only in controlled clinical trials [26–28].

In order to evaluate a sutureless anastomotic device, three aspects need to be taken into consideration: device–vessel wall connection, graft preparation and anastomosis’s biomechanical properties.

3.1. Device–vessel wall connection

There are three different solutions to anchor the connector to the vessel wall: pins, wall eversion and wall squeezing. Those solutions could simultaneously be present in the same device.

3.1.1. Pins

All the proximal connectors presented in Fig. 1 are anchored to the vein graft by means of pins (5–7) that go through the graft wall in intima–adventitia direction to minimize the risk of intimal flap (Fig. 3). Their traumatic action is generally comparable to that of 5-0 needle. The developed tensional force is excellent since the limiting factor is the graft tearing. The amount of metallic surface in contact with blood flow is small (Q-Cab) or zero (CoreLink) according to device design. The only limitation for pins is the wall stiffness. Moreover, if the anastomosis aborts, the vessel edges have to be trimmed.

3.1.2. Wall eversion

This solution requires the use of an anvil (metallic or plastic) to achieve the eversion. Everting the vessel assures that no adventitia will be left within the vessel lumen and reduces the risk of thrombosis. The tensional force is excellent but there are several potential limiting factors: graft wall has to be very soft and the eversion is a potential source of intimal lesions mostly on the edge that could lead to myointimal hyperplasia [29]. The necrosis of the everted vessel has been the primary cause of failure of the previous generation anastomotic devices. The histological studies on animal implants do not confirm this finding in the latest devices (GraftConnector) [29].
3.1.3. Wall squeezing

Vessel wall is squeezed between the inner and the outer device’s surface (Fig. 4). This technique is generally not traumatic to wall if the two surfaces are designed in a way that allows wall feeding, which means very small intima surface is covered by metallic parts and there is no occlusion of vasa-vasorum. A potential limiting factor is the presence of metal in the lumen that could promote myointimal hyperplasia, even if there is no experimental evidence of this issue. Another limiting factor is the wall thickness. It has to be in a precise range, generally between 2 and 4 mm according to the device design, otherwise the squeezing force is compromised.

As this is a key point for the anastomosis outcome, it could be helpful to measure aortic wall thickness before deploying the device with an epiaortic ultrasound or similar techniques. Even if the wall thickness is optimal, the tensional force is less than standard polypropylene running suture because disconnection occurs before vessel wall tearing. In case of anastomosis abortion, it is generally not necessary to trim the vessel edges.
No matter which type of device–wall connection is used, all devices guarantee the intima-to intima apposition, in agreement with the rules dictated by Carrel [1].

3.2. Graft preparation

Another important point in the evaluation of an anastomotic device is the manipulation that the graft has to go through to be loaded onto the deploying system. In some devices, the graft has to be mounted on a transfer sheet and this could cause intimal lesions that could affect the long-term patency, even if there is still no experimental evidence on this issue. Only sutures can be used to ensure the haemostasis on the vein graft side branches. Metallic clips would compromise the graft insertion in the deploying system. In some devices, the graft preparation requires the construction of the proximal anastomosis first, and this could be felt as a limitation by some cardiac surgeons.

3.3. Anastomotic biomechanics

Elastic properties of vessel wall are altered by vascular anastomoses and there are several studies that underline the importance of anastomotic compliance in the vascular reconstruction outcome [24,30]. The more the anastomosis is compliant, the less is the probability that it could develop a stenosis due to myointimal hyperplasia [31]. Unfortunately, there is no experimental study on sutureless anastomotic compliance. Baguneid found an improvement in para-anastomotic compliance when the vascular reconstruction was performed with non-penetrating clips versus polypropylene running suture, but those results have not been confirmed by other authors [30]. We could speculate that sutureless anastomosis is more compliant than a running suture anastomosis, since nitinol is more elastic than polypropylene, but the device itself probably makes the anastomosis more rigid than one constructed with the interrupted suture technique. The relative stiffness of the connector could be a potential cause of vessel wall atrophy. Daniel et al. [32] reported a severe vessel wall atrophy inside a rigid foreign body, and they postulate that this could occur each time a rigid body encloses a dynamic dilating structure.

Another point concerns the anastomotic angle. There are several studies demonstrating the importance of the anastomotic angle in the generation of vortex. Flow velocity in proximity to the wall is the main determinant of the shear stress, which is associated with intimal hyperplasia. Low velocity means low shear stress, which is considered as the first determinant of myointimal hyperplasia [31]. Computer fluiddynamic simulations [33] and haemodynamic studies [34] suggest that the best angle for a side-to-end or end-to-side reconstruction is between 30 and 45°. All the aortic connectors construct an anastomosis with a 90° angle that could predispose to graft kinking. Presently, we do not know if this angle has any impact on myointimal hyperplasia and if it has any clinical relevance.
In Table 1, we report a synoptic summary of characteristics of the main sutureless anastomotic devices.

4. Conclusions

Payr first expressed the concepts of wall eversion and pins in early 1900s to construct a vascular anastomosis with the non-suture technique. Those concepts have been expressed in several different ways in the last 100 years without reaching the clinical success, mostly because of technical and engineering limitations. Now they have been coupled with new materials and construction technologies to try to overcome all the problems previously described. The ideal anastomotic device has to provide minimal graft manipulation, no limitation in anastomotic timing, no material in the vessel lumen, optimal anastomotic angle and compliance. Generally, to become widely accepted, it must fulfill the following three essential characteristics: easy to handle, precision and, above all, evidence of long-term effectiveness. We definitely need prospective studies to prove the long-term effectiveness of these helpful devices.

References