

Biological Counterpulsation with Aortomyoplasty: Experimental and Clinical Results

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Abstract

Aortomyoplasty consists of wrapping the right Latissimus Dorsi (LD) muscle around the ascending aorta or the left LD around the descending aorta for compression during diastole. The aim of aortomyoplasty is to transform the ascending or descending aorta into a new cavity, which is contractile and hemo compatible. This technique produces a biological diastolic counterpulsation effect without damaging the aortic wall. Aortomyoplasty chronically reproduces the effects of the intra-aortic balloon pump [13] by the following mechanisms: 1) decreasing left ventricular afterload; 2) increasing the coronary perfusion pressure; 3) decreasing the peripheral vascular resistance. Our animal research studies began in our laboratory in 1988 [4] and the first clinical case using the aortomyoplasty was performed at the Broussais Hospital in November 1992 [3, 7]. Since then, four operations have been performed in our department and 32 worldwide.

After a mean follow-up of 19-months, the mean NYHA Functional Class improved from 3.6 preoperatively to 2.2 postoperatively ($p < 0.05$), as well as the overall quality of life in most patients. Improvements were seen in their physical activity, work performance and social activities. At the same time, hemodynamic and Echo-Doppler studies showed compression of the aorta with an increase in diastolic pressure during electrostimulation of the LD wrap. Long-term clinical follow-up and a larger patient population is necessary to define the role of aortomyoplasty in the treatment of severe cardiac failure.

Key words: aortomyoplasty, biological diastolic counterpulsation, cardiac assist, Latissimus Dorsi Muscle, neoventricle.

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Surgical technique

Aortomyoplasty utilizes the transposed LD flap in an extracardiac position and postoperatively the muscle is electrostimulated to produce a diastolic counterpulsation. The technique is completed without external manipulation of the heart. Dissection and mobilization of the LD, the implantation of the stimulating electrodes and the LD transposition inside the thoracic cavity are performed in a similar fashion to the dynamic cardiomyoplasty technique. Two surgical techniques are used to wrap the aorta:

1. The aortomyoplasty on the ascending aorta is first begun with careful dissection of the aortic root, which is best achieved through a standard median sternotomy. The pulmonary artery trunk is separated posteriorly from the aorta. The aorta is then wrapped with the right LD muscle in a counter-clockwise fashion and used as a ventricular chamber. The distal

portion of the LD can be separated into two bundles with the aim of covering the aorta proximally at the aortic root and distally, just adjacent to the innominate arterial trunk.

2. The aortomyoplasty on the descending aorta is performed through a standard left thoracotomy incision in the left fourth interspace. The portion of the descending aorta just distal to the left subclavian artery is dissected free. The first intercostal branches are separated and ligated, freeing a 8 cm long aortic segment for wrapping with the left LD.

To prevent spinal cord ischemia and postoperative paraplegia we recommend performing a preoperative aortic angiogram to identify any medullary vessels, especially the artery of Adamkiewicz (arteria radicularis magna) [11]. In cases of reduced aortic diameter, a piece of autologous pericardium can be used to widen and thereby, increase the volume of the "neoventricle". The

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autologous glutaraldehyde-treated pericardial patch is anastomosed to the aortic wall using a laterally-placed partial aortic cross-clamp, which avoids the need for extracorporeal circulation.

LD wrap electrostimulation

The electronic system for LD stimulation (Medtronic model 4750 electrodes and Cardiomyostimulator "Transform" System, or the new developed "LD-Pace II" Cardio-myo-synchro-stimulator, made by CCC Uruguay), as well as the implantation techniques are similar to those of Dynamic Cardiomyoplasty. However, the cardiomyostimulator program is specifically designed to assure electrostimulation of the LD wrap during diastole. This program also allows a transitory inhibition of muscle stimulation in cases of ventricular extrasystoles [6].

Experimental Studies

Four years of experimental research studies at the Broussais Hospital preceded the first clinical application of aortomyoplasty.

Short-term studies

Eight alpine goats (average weight 42 Kg) were used [4]. All interventions were performed under general anesthesia utilizing isoflurane inhalation. The right LD was dissected using a standard right oblique incision. The LD was then transferred into the thoracic cavity by resection of the right second rib. In four of these goats the diameter of aortic root was widened by surgical implantation of an autologous pericardial patch after treatment with 0.6% glutaraldehyde. The ascending aorta was then wrapped with the LD flap. It was then followed by counterpulsation electrostimulation using a Cardiomyostimulator connected to electrodes, which detected the QRS complex and electrodes stimulating the LD wrap.

Hemodynamic studies were performed with determination of cardiac output and aortic and pulmonary pressures, as well as, ventricular pressures (dP/dt). The diastolic counterpulsation of the transposed LD was carried

out using trains of impulses delivered at intra-train frequency of 30 Hz with an adjusted delay corresponding to the R wave to achieve an optimal increase during diastole. The percentage increases in endocardial viability index (DPTI/TTI) [15] was calculated according to assisted and non-assisted cardiac cycles (muscle stimulation to heart rate of 1:2) to the base line and after induction of acute cardiac insufficiency with intravenous administration of propranolol (3 mg/Kg/IV).

Results

The aortic diastolic counterpulsation with the electrostimulated LD showed a significant improvement in the DPTI/TTI index at base line and after cardiac insufficiency induction by propranolol (27% average improvement). A 42% improvement was found in the group, which underwent aortic root widening with autologous pericardium. In addition, when counterpulsation was permanent (1:1 ratio) a decrease in systemic vascular resistance and an increase in cardiac output was noted.

During the course of the experiments, we observed that electrostimulated LD contractions induced mechanical activity on the aorta comparable to homogeneous systolic activity. No modification, angulation of the aortic arch, nor any aortic valvular regurgitation were observed in the echocardiographic studies. In addition, no anticoagulants had been used during these experiments and no thrombus was observed in the aortic lumen.

Long term study

Five goats of the same species and average weight were used. An aortomyoplasty was performed utilizing the same technique employed in short-term studies. In all cases, the ascending aorta was widened with an autologous glutaraldehyde-treated pericardial patch, then wrapped with the right LD [5]. The transposed LD was then stimulated in synchrony with ventricular diastole. Sequential and progressive muscular stimulation was started with single pulses, followed by pulse trains two weeks later. Hemodynamic studies were performed

Table 1. Hemodynamic study in experimental chronic aortomyoplasty.

	BASELINE		HEART FAILURE	
	ST (-)	ST (+)	ST (-)	ST (+)
DPTI/TTI	1.13±0.13	1.39±0.18*	1.10±0.10	1.4±0.11*
CO (L. min)	7.92±1.6	7.84±1.1	3.68±0.55	5.58±1.04*
Systemic	879±135	903±121	1574±211	1134±249*
Vasc. Resist. (**)				
(* p < 0.05)				
(** dynes. sec. cm ⁻⁵)				
St (-): without LD electrostimulation				
St (+): with LD electrostimulation				

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at 12 and 24 months postoperatively, at basic line and after pharmacologic induction of acute cardiac failure with propranolol.

Results

Counterpulsation obtained in the ascending aorta significantly increased the cardiac output from 3.68 ± 0.55 to 5.58 ± 1.04 L/min ($p < 0.05$), and the systemic vascular resistance decreased from 1574 ± 211 to 1134 ± 249 dynes.s.cm⁻⁵ ($p < 0.05$). The DPTI/TTI index increased at base line from 1.13 ± 0.13 to 1.39 ± 0.18 ($p < 0.05$), and after induction of cardiac insufficiency from 1.10 ± 0.10 to 1.40 ± 0.11 ($p < 0.05$). Histological studies at 12 months (3 goats) and at 24 months (2 goats) did not show any evidence of aortic wall deterioration or local and systemic thromboembolic formations. Histology results indicated strong adhesion of the muscle graft to the aortic adventitia and to the autologous pericardial patch. No significant difference was found in the diameter of the ascending aorta measured immediately postoperatively or measured at the time of the histopathological studies: 18 ± 3 mm and 20 ± 2 mm, respectively.

World-Wide Clinical Experience

From November 1992 until December 1999, 36 patients (26 men, 10 women), with an average age of 54 ± 7 years, underwent aortomyoplasty worldwide. Demographically, places of treatment were at the Broussais Hospital, 4 patients [3, 7]; Marseille (La Timone Hospital), 4 patients [16]; London, 3 patients [22, 18]; Djedda in Saudi Arabia, 16 patients [19]; Buenos Aires, 8 patients [21]; and in La Coruna (Spain), 1 patient [12].

Etiology of heart failure was due to: ischemic cardiomyopathy (59%), idiopathic cardiomyopathy (34%) and Chagas Disease (7%). The majority of patients had radiologically significant cardiomegaly with an average cardiothoracic ratio of $67 \pm 7\%$ and echocardiographic diastolic left ventricular diameters of 81 ± 6 mm. All patients showed normal aortic valve function, and no calcification of the aortic wall.

Aortomyoplasty was performed on the ascending aorta in 25 patients and on the proximal descending aorta in 11 patients. In 8 patients, the aorta was widened with an autologous pericardial patch. The right LD was used to wrap the ascending aorta and the left LD was used to wrap the descending aorta. In 11 patients, the distal part of the right LD was separated into two bundles in order to cover the aortic root proximally and at the innominate artery distally.

After a mean follow-up of 19-months, the mean NYHA Functional Class improved from 3.6 preoperatively to 2.2 postoperatively ($p < 0.05$), as well as the overall quality of life in most patients. Improvements were seen in their physical activity, work performance and social activities. At the same time, hemodynamic and Echo-Doppler studies showed compression of the

aorta with an increase in diastolic pressure during electrostimulation of the LD wrap. Long-term clinical follow-up and a larger patient population is necessary to define the role of aortomyoplasty in the treatment of severe cardiac failure.

Minimally Invasive Surgical Approach

Recently, three clinical cases of ascending aortomyoplasty were performed using a minimally invasive surgical approach. The operations were done through a short 6 ± 2 cm skin incision. An inverse T and L median sternotomy extended from the sternal angle to the fourth intercostal space was used with preservation of both internal thoracic arteries. These incisions allowed adequate dissection of the ascending aorta to the origin of the innominate trunk. The aorta was completely wrapped over a 9 ± 2 cm long length. The right LD was previously dissected and transposed into the chest using a right thoracic cutaneous incision with resection of the anterior portion of the second rib. The operations were performed under good conditions, with excellent exposure of the aortic roots and the LD wrapping was easily performed through these small incisions.

Discussion

The intra-aortic balloon counterpulsation pump has become a widely utilized form of circulatory assistance since the pioneering work of Kantrowitz et al. in 1968 [13]. Its major limitations are its need of an external energy source with additional risks of infections, ischemic and thromboembolic complications of the lower limbs, and severe mobility restrictions for the patient, essentially being a valid short-term modality. Aortomyoplasty consists of a completely implantable autologous counterpulsation system that can be used for long-term circulatory support [2, 9, 14, 15, 17].

Recent progress in biologic and skeletal muscle stimulation have shown that skeletal muscle can be transformed into a fatigue-resistant muscle and provide a strong source of circulatory assistance [1, 8, 10].

The advantages of aortomyoplasty placed on the ascending aorta are the increased aortic diameter and it appears to be more effective when in close proximity the coronary ostia and the left ventricle. Consequently, the left ventricular afterload decreases. Physiologically, the aorta becomes a new hemocompatible contractile chamber. Hemodynamically, this combination of aorta and stimulated LDM produces a new ventricle and the failing left ventricle serves as a functional left atrium. An additional advantage of dynamic aortomyoplasty is that there is no external manipulation of the heart and no need for extracorporeal circulation [20].

Experimental models of aortomyoplasty associated with cardiac insufficiency have shown that when the aorta is enlarged, a significant improvement is seen in hemody-

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namic parameters. This means that a dilated ventricle is better assisted by a greater aortic volume [4].

Aortomyoplasty remains an option for severe chronic left ventricular insufficiency, unresponsive to a pharmacological treatment [23]. At the Broussais Hospital, aortomyoplasty is currently recommended to patients who present with a contraindication to cardiomyoplasty: i.e. significant mitral insufficiency associated with left ventricular failure, excessive dilatation of the heart, and calcification of the left ventricular wall.

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