Chronic Aortic Counterpulsation with Latissimus Dorsi: Clinical Follow-Up. Cardiomyoplasty Comparison

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Abstract
Dynamic aortomyoplasty is an alternative technique to heart transplantation. The goal of our study was to evaluate the benefits of aortic counterpulsation obtained by dynamic aortomyoplasty in patients with heart failure refractory to pharmacological treatment and contraindications to heart transplant or cardiomyoplasty.

In this study we compared preoperative and postoperative data of selected patients submitted who were treated with dynamic thoracic aortomyoplasty. This surgical technique wrap the right latissimus dorsi muscle flap around the ascending aorta. This muscle flap was electrically stimulated during diastole, following a muscle-conditioning protocol, to obtain diastolic augmentation. At twelve months follow-up period we evaluated, invasively and noninvasively, the hemodynamic and clinical effects of aortomyoplasty.

We observed a significant decrease in the number of hospitalizations (p<0.001), NYHA functional class (p<0.001), left atrial diameter (p<0.05), wedge pressure (p<0.05), left ventricular diameter (p<0.05) and pulmonary artery systolic pressure (p<0.05); and a significant increase in the 6-minute walking test (p<0.001), cardiac index (p<0.01), noninvasive evaluation of diastolic augmentation (p=0.01), left ventricular shortening fraction (p<0.05), and radioisotopic left ventricular ejection fraction (p<0.05). We also found a non significant decrease in peak oxygen consumption (p=0.05).

This nine patients operated with aortomyoplasty was compared with sixteen patients treated with cardiomyoplasty at twelve months of follow-up.

Dynamic biologic assistance with latissimus dorsi in heart failure, either aortomyoplasty or cardiomyoplasty in selected patients with severe heart failure, resulted in an important improvement of hemodynamic parameters, heart functional data and clinical functional, without significant differences between the results of both techniques.

Key words: aortomyoplasty, cardiomyopathy, cardiomyoplasty, latissimus dorsi muscle, skeletal muscle.

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Congestive heart failure is an important cause of morbidity and mortality in the Western world. The treatment of severe heart failure has undergone several changes: administration of new drugs, cardiac transplantation and ventricular assist devices, resulting in a significative improvement in terms of quality of life and survival [22]. Nevertheless, an increasing number of patients with cardiac diseases develop heart failure every year [12]. At present, several mechanical circulatory assistance devices are used as alternative treatments to provide bridge-to-transplant or even bridge-to-recovery for patients with severe heart failure refractory to pharmacological treatment.

Chronic cardiac failure is not only a medical problem but also a social and economic concern, because many patients cannot benefit from cardiac transplant because organs need to come from healthy bodies; in addition, immunosuppression and scarcity of organ donors restrict this option [1].

Arterial counterpulsation has been used for treating acute severe left ventricular dysfunction in patients with refractory heart failure. Indeed, arterial counterpulsation using intra-aortic balloon pump has been widely used during the last 20 years in acute left ventricular failure.

Recently, patients suffering from refractory cardiac failure have been also treated with a biologic assistance
method called “dynamic aortomyoplasty” [7, 27]. This method consists in diastolic counterpulsation of ascending or descending aorta through stimulation of latissimus dorsi muscle flap wrapped around it. However, not very detailed clinical results or long term follow-up reports have been published, to the best of our knowledge [8, 26].

The goal of this study was to evaluate hemodynamic, functional and clinical effects of dynamic thoracic aortomyoplasty in a group of carefully selected patients with severe heart failure refractory to pharmacological treatment and contraindications for heart transplant or cardiomyoplasty.

Materials and Methods

Population study

Nine patients (8 males) affected by severe chronic severe heart failure were referred to President Perón Hospital. Mean age was 55.4±7.4 years (69-44 years). All patients had previously had several episodes of acute pulmonary edema, despite the fact that all of them were under optimal medical therapy (low sodium diet, digitalis, vasodilators, beta-blockers, angiotensin converting enzyme inhibitors and diuretics: furosemide and hydrochlorothiazide and/or amiloride and/or spironolactone).

In spite of this personalized therapy, these patients were admitted to hospital 4.0±1.6 times, during the year previous to surgery, due to congestive heart failure. Dilated cardiomyopathy resulted from Chagas’ disease in 4 patients, idiopathic dilated cardiomyopathy in 3 patients and coronary artery disease in 2 patients. Associated cardiac pathologies were: severe mitral regurgitation (n=6), moderate mitral regurgitation (n=3), severe tricuspid regurgitation (n=4) and mild tricuspid regurgitation (n=5). Aortic wall was explored with radioscopy and echographic studies and no calcifications were found in these patients. Pre-operative patient data included NYHA Class III in eight patients and Class IV in one patient. All patients were submitted to diagnostic coronary angiography and two showed severe stenotic lesions with no myocardium viability detected by radiisotopic ventriculogram and exercise thallium-201 scintigraphy. Left ventricular ejection fraction was assessed through radioisotopic studies. The aortomyoplasty procedure was decided based on previously developed criteria (Table I).

All patients from this series had been rejected for cardiac transplantation due to aging (n=2), or Chagas’ disease (n=4) or psycho-social factors (n=3).

All patients in this series had been rejected for cardiac transplantation due to aging (n=2), or Chagas’ disease (n=4) or psycho-social factors (n=3). Severe mitral regurgitation or cardiac enlargement excluded these patients from dynamic cardiomyoplasty procedure. The preoperative hemodynamic and heart functional data of the patients are presents in Table II.

All data were obtained in compliance with protocols approved by the investigational review board of our institution. The patients were informed of the characteristics of the procedure and its risks and written consent was always obtained from each patient. During the whole period of therapy, all patients received psychological assistance.

Surgical procedure

In all patients, a balloon-tipped catheter recorded the right atrium pressure, pulmonary pressures, wedge pressure and cardiac index. Afterwards, with the patient on left lateral decubitus, a wide cutaneous incision was made between the left axillary region and the posterior iliac crest. The right latissimus dorsi muscle was dissected and special care was taken to preserve its neurovascular bundle. Two pacing electrodes (Medtronic

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**Table I. criteria for selection of patients.**

<table>
<thead>
<tr>
<th>Inclusion criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dilated cardiomyopathy with heart failure NYHA III-IV.</td>
</tr>
<tr>
<td>Left ventricular ejection fraction &lt; 30%</td>
</tr>
<tr>
<td>Peak VO₂ &lt; 20 ml/Kg/min</td>
</tr>
<tr>
<td>Contraindication for heart transplantation</td>
</tr>
<tr>
<td>Contraindication for cardiomyoplasty</td>
</tr>
</tbody>
</table>

**Exclusion criteria**

- Aortic regurgitation
- Aortic calcification
- Aortic aneurisma or dilatation >40 mm
- Refractory Hypertension (DBP > 90 mmHg)
- Arrhythmia refractory to drug treatment
- Neuromuscular disease

NYHA: New York Heart Association functional class, VO₂: oxygen consumption, DBP: diastolic blood pressure.

**Table II. Comparative analysis of pre-operative and 12-month post-operative data in patients after aortomyoplasty.**

<table>
<thead>
<tr>
<th></th>
<th>Pre AMP</th>
<th>Post AMP</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>NYHA Functional Class</td>
<td>3.1±0.4</td>
<td>1.1±0.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>6 Minutes Walking Test (m)</td>
<td>394±84.6</td>
<td>525±97.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Peak VO₂ (ml/Kg/min)</td>
<td>12.2±3.6</td>
<td>14.1±4.5</td>
<td>0.05</td>
</tr>
<tr>
<td>Cardiac index (L/min/m²)</td>
<td>2.0±0.3</td>
<td>2.65±0.44</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

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Muscle stimulation protocol

Skeletal muscle flap electrostimulation started two weeks after surgery and a progressive muscle-conditioning protocol was followed, which was fulfilled in two months. This stimulation was similar to the one performed in cardiomyoplasty, but it took place during the diastolic period of cardiac cycle.

Once the protocol was finished, stimulation started with the following characteristics: voltage: 3.5V, pulses per burst: 6, rate mode: 1:2 with heart rate, and synchronization delay: 230 to 490 milliseconds. The delay between ventricular sensed contraction and muscle burst was adjusted through echocardiography to provide an exact synchronization between muscle flap contraction and ventricular diastole. The burst of pulses was triggered after aortic valve closure.

Patient follow-up

Once the progressive muscle-conditioning protocol was finished, 4 patients were submitted to aortic cineangiographic studies in order to detect stenotic changes in aortic lumen. The aortic pressure curve and its temporal relationship with R wave of surface electrocardiogram also were recorded. The postoperative hemodynamic and heart functional data of these patients were obtained at 12-month follow-up and they were compared with the corresponding pre-operative data.

The extent of diastolic aortic augmentation was measured noninvasively by a counterpulsation index derived from diastolic and systolic areas beneath aortic pressure curve (DABAC/SABAC). To assess arterial pressure waves we used a technique for non-invasive beat-to-beat blood pressure monitoring in ambulatory patients. Devices for clinical use are called Finapres (2300 Finapres, Ohmeda, CO, USA) or Portapres (Portapres Model-2, TNO-TPD Biomedical Instrumentation, Amsterdam, The Netherlands). This technique comprehends the Penaz volume-clamp approach combined with an infrared plethysmography that keeps volume of finger artery at a preset value during testing time. Finapres records of finger artery pressure waves and surface electrocardiogram were obtained in all patients during basal state. These signals were digitized in a compatible IBM PC computer. DABAC/SABAC index was calculated with on-line data acquisition of electrocardiogram and pressure signals, obtained with a Keithley DAS802 data acquisition board, driven by a specially written program in Visual Basic for Windows. Recording parameters were sampling frequency: 150 Hz, acquisition channels, 3; samples per acquisition, 800; and synchronism signal, taken from pulse generator. The DABAC/SABAC index was calculated through a program specifically developed in C++ language. This program was used on an IBM PC compatible computer.

The nine patients operated with aortomyoplasty was compared with sixteen patients treated with cardiomyoplasty at 12 months of follow-up (Table III).

Calculations and statistical treatment

The DABAC/SABAC values were determined considering the relationship between systolic area beneath the arterial pressure curve, enclosed between the dichrotic notch and the ascending foot of aortic pressure wave of the following cardiac cycle, and diastolic area beneath the arterial pressure waves, enclosed between the ascending foot and the dichrotic notch of the aortic pressure curve. Values reported are expressed as mean ± standard deviation. Statistical significance was assessed with paired Student’s t-test. A 95% confidence limit was chosen as indicator of statistical significance (p<0.05).

Results

There were no intraopereative or early post-operative deaths in this series. No in-hospital mortality was registered, and the immediate post-operative course was uneventful in general. Inotropic pharmacological support was routinely provided during 48 hours, and no intra-aortic counterpulsation was necessary in any case. All of the patients recovered from surgery was satisfactorily and each of them remained 5 days in the intensive care...
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The post-operative hospitalization average was: 15.5±4 days.

Infection of surgical incision and cardiomyostimulator abdominal wall pocket developed in only one patient, and it was successfully treated with antibiotic therapy. Two patients died at two and three months follow-up, due to ventricular arrhythmia, although they were receiving medical therapy for severe ventricular arrhythmias and atrial fibrillation. Seven patients completed the muscle-conditioning period and they were followed during 18.1±10.7 months.

Four patients needed inotrope therapy one month before aortomyoplasty. All patients received digoxine, enalapril and diuretics before surgery. Three patients were administered amiodarone before aortomyoplasty. Two patients received oral anticoagulation and the other four patients were on aspirin before surgery. All patients received the same pharmacological treatment after aortomyoplasty. Diuretics doses were reduced in every patient during the post-operative period.

At 12 month follow-up, clinical, hemodynamic and functional evaluation of these patients showed an improvement in almost all parameters (Table II). Hospitalizations due to congestive heart failure diminished from 4.0±1.6, during the year previous to aortomyoplasty, to 0.4±0.7, during the first year after surgery (p=0.001). The noninvasive counterpulsation index (DABAC/SABAC) showed a significative increase between assisted and non-assisted cardiac cycles (Table IV). Doppler echocardiography studies showed a decrease in severity of mitral and tricuspid regurgitation in all surviving patients, if compared with the ones obtained previous to aortomyoplasty. Diuretics doses were reduced in every patient during the post-operative period.

In four patients the aortic diastolic counterpulsation was observed with aortic cineangiographic studies. No thrombosis was found in ascending aorta and aortic valves were anatomically and functionally normal. No further alteration was observed in these invasive studies.

Table III. Comparative analysis of pre-operative and 12-month post-operative in patients after aortomyoplasty and cardiomyoplasty.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>AMP Preop</th>
<th>AMP Postop</th>
<th>CMP Preop</th>
<th>CMP Postop</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC (NYHA)</td>
<td>3.1 ± 0.4</td>
<td>1.1 ± 0.4#</td>
<td>3.1 ± 0.3</td>
<td>1.7 ± 0.6*</td>
</tr>
<tr>
<td>Hospitalizations (nbr/p/yr)</td>
<td>4.0 ± 1.6</td>
<td>0.4 ± 0.7#</td>
<td>2.0 ± 0.7&amp;</td>
<td>0.4 ± 0.5*</td>
</tr>
<tr>
<td>LA Diameter (mm)</td>
<td>56.5 ± 5.6</td>
<td>48.2 ± 11.5</td>
<td>55.5 ± 10.0</td>
<td>53.2 ± 10.0</td>
</tr>
<tr>
<td>LV Diastolic Diameter (mm)</td>
<td>77.8 ± 11.3</td>
<td>71.5 ± 9.2</td>
<td>72.7 ± 7.0</td>
<td>72.3 ± 8.0</td>
</tr>
<tr>
<td>LV Shortening Fraction (%)</td>
<td>13.2 ± 5.3</td>
<td>18.7 ± 6.4#</td>
<td>15.6 ± 4.0</td>
<td>20.6 ± 5.0*</td>
</tr>
<tr>
<td>LV Ejection Fraction (%)</td>
<td>21.0 ± 6.6</td>
<td>34.2 ± 14.5#</td>
<td>23.6 ± 3.0</td>
<td>29.7 ± 5.0*</td>
</tr>
<tr>
<td>6 min Walking Test (m)</td>
<td>394 ± 85</td>
<td>525 ± 98</td>
<td>332 ± 127</td>
<td>421 ± 102</td>
</tr>
<tr>
<td>VO₂ max (ml/Kg/sec)</td>
<td>12.2 ± 3.6</td>
<td>14.1 ± 4.5</td>
<td>13.3 ± 3.0</td>
<td>14.3 ± 3.0</td>
</tr>
</tbody>
</table>

References: AMP: aortomyoplasty; CMP: cardiomyoplasty; FC (NYHA): functional class (New York Heart Association); LA: left atrial; LV: left ventricular; VO₂: oxygen consumption.

Table IV. Non-invasive evaluation of diastolic augmentation in aortomyoplasty.

<table>
<thead>
<tr>
<th></th>
<th>NON-ASSISTED</th>
<th>ASSISTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient # 1</td>
<td>1.57</td>
<td>1.66</td>
</tr>
<tr>
<td>Patient # 2</td>
<td>2.03</td>
<td>2.33</td>
</tr>
<tr>
<td>Patient # 3</td>
<td>1.24</td>
<td>1.48</td>
</tr>
<tr>
<td>Patient # 4</td>
<td>1.13</td>
<td>1.33</td>
</tr>
<tr>
<td>Patient # 5</td>
<td>2.22</td>
<td>2.52</td>
</tr>
<tr>
<td>MEAN±SD</td>
<td>1.64±0.48</td>
<td>1.86±0.59*</td>
</tr>
</tbody>
</table>

Diastolic augmentation evaluated through diastolic/systolic areas beneath the arterial pressure curve relationship in assisted and unassisted cardiac cycles. Assisted vs. non-assisted values show a significative increase of diastolic augmentation in patients submitted to aortomyoplasty procedure.

An invasive aortic pressure curve measurement was registered in each patient (Figure).

Discussion

Biologic aortic counterpulsation is a well-known technique, introduced in 1958 by Kantrowitz [13]. Human application with intraaortic balloon pump results in beneficial hemodynamic effects, such as reduction of myocardial oxygen consumption, augmentation of coronary perfusion and increase of cardiac output [11, 14, 23]. Balloon counterpulsation can be used for short or intermediate term circulatory assistance. During the last decade, dynamic thoracic aortomyoplasty has been introduced as a new surgical technique to treat patients with severe heart failure. This is an attractive alternative because of the non-cardiac involvement of this surgical technique. Nature provides an example of chronic counterpulsation: diastolic augmentation is always observed in kangaroo’s aortic pressure signal [16]. Nevertheless, not very detailed clinical results and long term...
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follow-up with clinical, hemodynamic and functional evaluations pre-operatively and post-operatively have been published.

Another series of surgical approaches to severe heart failure refractory to pharmacological treatment have been published. Mitral regurgitation is usually found in patients with severe left ventricle dysfunction and dilatation. Bolling reported that patients with dilated cardiomyopathy and mitral regurgitation improved after mitral repair [4]. Aortomyoplasty also causes a reduction in patients’ afterload, which improves mitral regurgitation as Bolling technique does, with similar clinical results. The Batista procedure, consisting in partial left venticulectomy in dilated cardiomyopathy, still shows a high surgical mortality: 15%, and a poor life expectancy at twelve months follow-up: 56% [32].

Aortomyoplasty has been performed in ascending aorta and in descending thoracic aorta [2-3, 15]. We preferred ascending aorta to descending aorta in order to avoid the risk of paraplegia due to spinal chord ischaeemia. By using ascending aorta, we hoped to gain maximal mechanical advantage of placing a counterpulsation as close as possible to pulse origin. Also, the diastolic augmentation of coronary blood flow is optimized. Furthermore, diameter of ascending aorta is larger than that of descending aorta.

The progressive muscle-conditioning protocol was designed to induce fast fatigue-resistant muscle with advantageous biomechanical characteristics for the purposes of aortomyoplasty [18-21, 31]. The total stimulation threshold, the minimum voltage needed for a total muscle contraction, was measured during surgical procedure and it was never increased, as high voltage electromyostimulation has been related to muscle fibrosis. The stimulation rate was 1:2 with heart rate, to avoid overstimulation. Hemodynamic and doppler echocardiography studies demonstrated the diastolic augmentation and compression of aorta during latissimus dorsi muscle flap electrostimulation.

The latissimus dorsi muscle flap is usually used in cardiomyoplasty [6, 10]. Due to the enlargement of ventricular diameters in end stage heart failure, pericardial patches are sometimes necessary to obtain an optimal cardiac wrapping [9, 29]. Nevertheless, in aortomyoplasty, total mass of skeletal muscle required to provide an adequate counterpulsation is largely provided by the latissimus dorsi and no supplementary patches are necessary. Aortic enlargement by means of a pericardial patch was not necessary in our patients, because the aortic root diameter was appropriate. Perhaps the volume of skeletal muscle is an important factor in long-term integrity of pedicled flaps under electrical stimulation.

During follow-up, diuretics doses were reduced in every patient, and all of them used lower doses of their optimal pharmacologic treatment than they had used before aortomyoplasty. We also observed a decrease in left atrium and right ventricular sizes, which was related to a decrease in systolic pulmonary artery pressure, and a decrease in cardiothoracic index. Doppler echocardiography showed a decrease in severity of mitral and tricuspid regurgitation. Left ventricle size, measured with echocardiography, showed a decrease, which could be considered a trend, similar to the one observed with cardiomyoplasty. We also found an increase in 6 minutes walking test results and in left ventricle shortening and ejection fractions. The increase observed in oxygen consumption test results was comparatively lower, perhaps due to peripheral mechanisms. A significative increase was found in non-invasive counterpulsation index values between assisted and non-assisted cardiac values. This objective technique, based on the Penaz principle, could be useful in evaluating long term evolution of chronic counterpulsation [5, 17]. On the other hand, the diastolic changes observed in the invasive records of aortic pressure signal (n=5) seemed minimal and no statistical studies were performed. The data supported that the procedure resulted in a decrease of the number of hospitalizations due to congestive heart failure.

In conclusion, dynamic thoracic aortomyoplasty seems to be an efficient technique to assist patients suffer from severe heart failure refractory to drug treatment and have contraindications for cardiomyoplasty or heart transplant. Our treatment of end-stage cardiac failure with aortomyoplasty in carefully selected patients re-
sulted in an effective improvement of clinical, hemodynamic and heart functional parameters.

Current clinical evaluation shows an improvement of functional class and quality of life of those patients submitted to aortomyoplasty. A larger clinical experience, a randomized study and a longer follow-up with periodic clinical controls and hemodynamic and functional evaluations would be useful to evaluate long-term effects of this technique in order to confirm its clinical relevance [24-25, 28, 30].

On the other hand dynamic biologic assistance with latissimus dorsi in heart failure, either aortomyoplasty or cardiomyoplasty in selected patients with severe heart failure, resulted in an important improvement of hemodynamic parameters, heart functional data and clinical functional class, without significant differences between the results of both techniques.

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References

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