Aortomyoplasty

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Abstract

Aortomyoplasty is a surgical procedure which should sustain the hemodynamic effects of intra-aortic balloon pump for the long run. This operation will probably be suitable for end-stage heart failure patients. The experimental results are encouraging but further experimental and clinical experience is required to evaluate the use of the procedure.

Key words: aortomyoplasty, skeletal muscle, congestive heart failure, cardiomyoplasty.

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Based on the principle of intra-aortic balloon pumping, dynamic aortomyoplasty is forwarded as a promising procedure for the long-term treatment of congestive heart failure. The surgical intervention involves thoracotomy, whereby a skeletal muscle (the right or left latissimus dorsi) is wrapped around the aorta (ascending or descending) and subsequently stimulated electrically to make it contract in counterpulsation with the spontaneous heart systole [8, 38]. This aortic assist priciple is intended to decrease the afterload prior to systole, and to increase coronary blood flow during diastole, i.e. the same objectives as the intra-aortic balloon pump (IABP). Whereas IABP offers a temporary support, aortomyoplasty might represent a permanent intervention. The objective of this review is to summarize the experimental and the limited clinical results, and to delineate how to proceed towards clinical applications.

The Need for Aortomyoplasty

Congestive heart failure constitutes a major health care problem with for instance more than 2 million US patients. The majority of these patients has predominantly left ventricular failure, with preserved right ventricular function, which is a prerequisite for selective left ventricular assistance. Congestive heart failure is characterized by impaired quality of life and markedly shortened life expectancy [13, 37]. According to the Framingham heart study, the one year survival rate of patients with a new onset of congestive heart failure was 57% for men and 64% for women, and the five year survival was 25% and 38%, respectively [25]. Optimal medical treatment of patients with congestive heart failure improves the quality of life and survival rates, but mortality is still unacceptably high [47]. Heart transplantation, as the most accepted and well known type of intervention, leads to a higher life expectancy and a better quality of life for these patients [23]. However, the lack of donors and the high percentage of patients who are not suitable for heart transplantation reduce the possibilities of performing this procedure on a large scale [19].

Dynamic cardiomyoplasty is another surgical treatment for patients who are ineligible for heart transplantation [5]. Nevertheless, it is clear from the immediate and long term results of dynamic cardiomyoplasty, that this procedure is not suitable for end-stage heart failure patients in New-York-Heart-Association (NYHA) Class IV, in patients with a significant mitral valve regurgitation, or in patients with pulmonary hypertension [35]. Other alternatives such as the total artificial heart [28], heart xenografting [24] and the skeletal muscle ventricle [14,40], are still in an experimental stage. The dynamic aortomyoplasty, still in the experimental and early clinical stage, might offer a surgical treatment for the end-stage heart failure patient when cardiomyoplasty is contraindicated [9].

Historical Review

The idea of using skeletal muscle as a source of energy to augment failing hearts dates back to 1959, when Kantrowitz and McKinnon demonstrated diastolic augmentation while stimulating a wrapped diaphragm muscle around the descending aorta [27]. This muscle was stimulated in counterpulsation with the spontaneous heart beats. The main obstacle to this procedure was the inevitable occurrence of skeletal muscle fatigue several minutes after continuous stimulation. The breakthrough was achieved with the report of Salmons and co-workers, describing the possibility of converting skeletal muscle to a fatigue-resistant muscle by continuous slow electrical stimulation [42, 43]. The second major step forward was the development of a special stimulator capable of producing a burst of electrical pulses which mimic the long titanic contraction of the myocardium. This stimulator is also capable of sensing spontaneous heart beats which permit synchronization of the counterpulsating contraction [18]. Finally, the latissimus dorsi muscle (LDM) was accepted as the preferable muscle for both aorto- and cardiomyoplasty. The first clinical application of these achievements was the dynamic cardiomyoplasty done by Carpentier and Chachques 1985 [6]. Since then numerous successful experimental and clinical cases have been reported using dynamic cardiomyoplasty [3].

Counterpulsation using the IABP has proven to be a useful clinical tool for the support of left ventricular heart failure patients. Both decreases in peak systolic pressure, in myocardial oxygen consumption, and in LV wall stress, and increases in mean diastolic blood pressure and coronary blood flow have been described [22, 29, 36]. However, long-term support by IABP is not feasable due to the occurrence of infection and thromboembolic events [21]. This has raised new interest in the concept of diastolic augmentation using the conditioned skeletal muscle as a power source for external aortic counterpulsation. Since 1990 new experimental and preliminary clinical data regarding dynamic aortomyoplasty have been presented.

The Surgical Technique

At present there are two methods to perform dynamic aortomyoplasty namely wrapping the latissimus dorsi muscle around the ascending aorta using the right latissimus dorsi muscle [Fig. 1], or wrapping the descending aorta using the left latissimus dorsi muscle [Fig. 2]. The first part of the operation, the preparation of the latissimus dorsi muscle, is identical to the first part of the cardiomyoplasty procedure and has been described in detail by Chachques and co-workers [10]. Under general anesthesia, the patient is initially placed in the left or right lateral position according to the latissimus dorsi which is going to be used. The latissimus dorsi muscle is then exposed through a flank incision extending from the axilla to halfway the 12th rib and the muscle is freed from the surrounding tissue while ligating and cutting the collateral blood vessels that mainly supply its distal part. During this procedure care is taken that the proximal neurovascular pedicle is preserved. Subsequently, two stimulating electrodes are implanted in the muscle, whereby the proximal negative electrode is positioned in close proximity to the course of the main nerve branches, and the distal positive electrode is implanted also transversely into the muscle 4-6 cm more distally. At this stage, the muscle stimulation threshold and full muscle recruitment are obtained using an external stimulator.

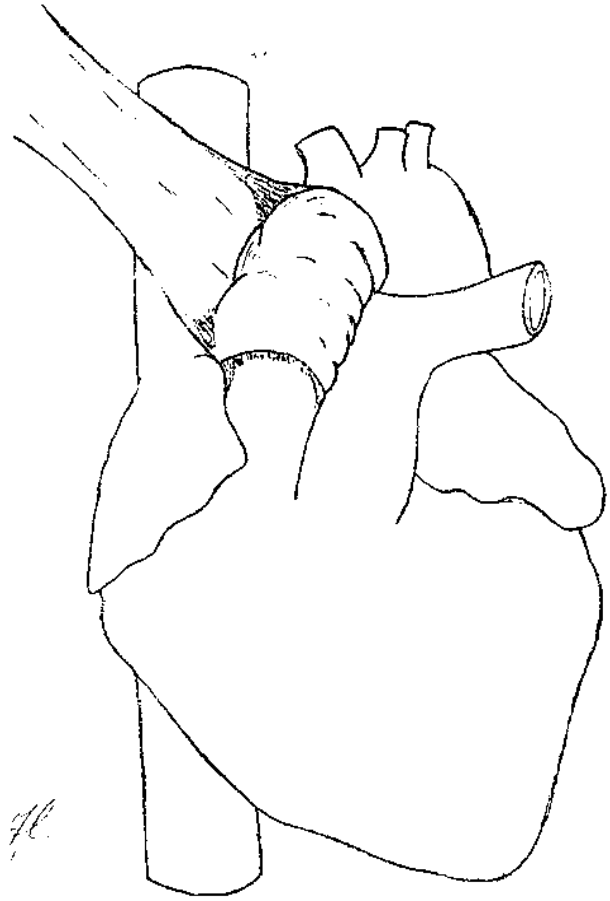

Figure 1. Ascending aortomyoplasty. The right latissimus dorsi muscle is wrapped around the ascending aorta.

The second stage of the operation is the wrapping around the aorta and varies technically according to the aortic area intended to be wrapped. Chachques and coworkers originally proposed the ascending aorta for aortomyoplasty and based their advise on the assumption that the major benefits of aortic counterpulsation will be obtained if performed as close as possible to the aortic valve [9] (figure 1). In that case, a right LDM is used because of preferred anatomical orientation and proximity. Aortic root enlargement with a pericardia! patch of about 250 cm was also used by Chachques in animal studies in order to increase the amount of blood displaced during the aortic counterpulsation by the LDM contraction. Another surgical adaption is that when the ascending aorta is relatively short, the muscle can be split and wrapped proximal and distal to the innominate artery around the aorta.

Wrapping of the descending thoracic aorta has been the other option to perform aortomyoplasty (Figure 2). This technique may have advantages if compared with the ascending aortomyoplasty, since the portion of the aorta suitable for the skeletal muscle wrapping is longer. In case of a re-operation after previous cardiac surgery, both resternotomy and mediastinal dissection are avoided in this approach. Muscle preparation and wrapping of the aorta can be achieved through a single skin incision, which is an

Figure 2. Descending aortomyoplasty. The left latissimus dorsi muscle is wrapped around the descending aorta.

advantage because it is a faster and less traumatic procedure [34]. Nevertheless, descending aortomyoplasty usually requires the ligation of one or more intercostal arteries with the subsequent potential complication of postoperative neurological disorders (Adamkiewitz artery). Flum recently reported a modification of the descending aortomyoplasty operation in an attempt to preserve the intercostal arteries [20]. Indeed, the use of several muscle splittings at the level of the intercostal artery and of peri - cardial "bridges" to connect posteriorly the LDM to the wrapped aortic portion, has been shown. Furthermore, he evaluated the use of the Serratus muscle for descending aortomyoplasty, with less good results in comparison with LDM aortomyoplasty [7].

An apparent drawback of aortomyoplasty may be represented by the need of muscle trimming due to the redundant mass of the LDM compared with the limited portion of the aorta to be wrapped. Nevertheless, the most powerful area of the muscle (the proximal) is used for the counterpulsation, taking into account that the distal part is often subjected to ischemia caused by the surgical harvesting, and therefore usually damaged and ineffective in terms of muscle performance. The evaluation of the effects of different aortomyoplasty configurations has been an additional target of several investigators. Pattison and collaborators showed the efficacy of descending aortomyoplasty according to varied wrapping techniques [38]. He showed that wrapping the aorta twice with a trimmed LDM in a clockwise direction, and suturing the muscle to itself, provided the best diastolic augmentation. Recently, Cmolik reported a comparison of the modified wrapping modalities by the mobilized skeletal muscle, namely the "helical", the "circumferential", and the "wringer" configurations [12]. He showed that the application of the "wringer" technique (LDM splitted in 2 parts and wrapped in an opposite way around the aorta) provides a more forceful and effective counterpulsation of the aorta.

A preliminary report on clinical application of aortomyoplasty has been recently presented by Messana and Raffa [34, 41]. Messana performed a modified aortomyoplasty of the initial descending aorta with the left LDM in 4 patients. The technique described consists of the passage of the mobilized left LDM posteriorly to the aorta, and then suturing the distal part of the muscle to the posterio thoracic wall ("scarf technique"). This technique is based on the concept of the pulling action obtained by the LDM contraction, and not on a squeezing contribution of the wrapped muscle, which are the two probable mechanisms of action of aortomyoplasty. Cernaianu showed reduction of the aortic lumen during LDM contraction by intravascular echo supporting the concept of external counterpulsation by a wrapped skeletal muscle [7].

Unless concomitant cardiac surgery requires ECC, cardiopulmonary bypass is usually not necessary for the aortomyoplasty procedure, but nevertheless it should always be available on standby.

It is clear that at present the aortomyoplasty surgical procedure is still under experimental and clinical evaluation and therefore the most optimal surgical technique can not yet been presented.

Conditioning of Skeletal Muscle

From the dynamic cardiomyoplasty experience both preclinical and clinical techniques have been implemented in the aortomyoplasty procedure. This holds true for the surgical handling of the skeletal muscle *(vide supra),* but also for the electrical stimulation of the skeletal muscle. The similarity regards firstly the conditioning of the muscle to obtain a fatigue resistant muscle, and secondly to the synchronized electrical stimulation to obtain the most optimal cardiac assist.

Conditioning of the skeletal muscle, also called "training" or "transformation", is necessary, because of the well known differences between skeletal and cardiac muscles [1]. In the human latissimus dorsi 50-60% of the muscle fibers are type II [26, 46]. Therefore, the human latissimus dorsi tends to fatigue after some minutes of continuous work.

Following the reports of Salmons and co-workers, conditioning protocols have been developed to transform fast twitch type II muscle fibers into slow twitch type I muscle fibers. After twelve weeks of conditioning, the majority of the muscle fibers are slow twitch type I and the muscle is relatively fatigue resistant [31, 48].

Whether the fatique resistancy occurs to the same extent in patients, and more basically, whether muscle transformation occurs in patients is as yet unknown [16]. There may be a disadvantage of aortomyoplasty candidates who are in NYHA class IV as the type I fibres in the LDM appears to be lower than in controls (32 ± 11% vs 52 ± 14%) [15]. Together with this fiber type transformation, two other less desirable effects occur. Firstly, reduction in contractility and power has been reported to an extent, that augmentation by skeletal muscle stimulation can only be limited [32,33]. The simultaneous doubling of contraction and relaxation time is of special importance in aortomyoplasty, amongst others because the aim of abrupt deflation of the lABP-balloon is to reduce the afterload just prior to LV-ejection. Retarded relaxation of the LDM will hamper this afterload reduction, and will thereby diminish the effect of counterpulsation [39]. Another sequela is the late damage of the LD muscle [32]. To prevent this chronic muscle damage the conventional stimulation has been adapted by reducing the LD muscle frequency of contraction.

Electrical Stimulation of the Latissimus Dorsi Muscle

After two weeks of delay for the flap to recover (vascular delay) and for the formation of adhesions between the LDMF and the aorta, the conditioning protocol is started [9]. The conditioning protocol takes twelve weeks and is implemented by gradually increasing the number of electrical pulses in a burst every two weeks. The final stimulator setting is usually six pulses in a burst duration of 185 milliseconds, every second spontaneous beat for a high heart rate. There is a theoretical advantage in the possibility to adjust the spontaneous beat to muscle stimulation ratio in different heart rate ones according to the physiologic state of the patient, e.g. during sleep 1:6 and during exercise 1:2. The exact stimulation parameters and voltage of the pulse are adjusted individually for each patient.

Experimental Results

Both ascending and descending aortomyoplasty reveal significant hemodynamic improvements while stimulating the wrapped latissimus dorsi muscle (LDM) around the aorta. Chachques and co-workers demonstrated significant diastolic augmentation in goats while the LDM was stimulated around the ascending aorta up to a diastolic pressure of 90 mmHg (baseline 115/65 mmHg) [8]. The results were even better when using a pericardial patch to enlarge the ascending aortic cavity, when diastolic pressures reached 105 mmHg (baseline 105/70 mmHg) (figure 3). There was a significant increase in the subendocardial viability index (diastolic pressure-time index/systolic tension-time index), from 29% and up to 42% with the aortic patch and while reducing cardiac contractility by a high-dose of propranolol. The same group presented the experimental results 12 and 24 months postoperatively with a conditioned LDM thus representing the clinical situation [10]. Two years after the operation diastolic augmentation could still be observed (figure 4). While inducing cardiac failure by propranolol, stimulation of the LD muscle resulted in a significant decrease in left ventricular end-diastolic pressure and systemic vascular resistance and a significant increase in cardiac output from 3.6 ± 0.5 to 5.5 ± 1.0 L/min. The examination of histologic structure showed preservation of the aortic wall tissue and tight adhesions between the aortic adventitia and the LDM two years after the wrapping procedure.

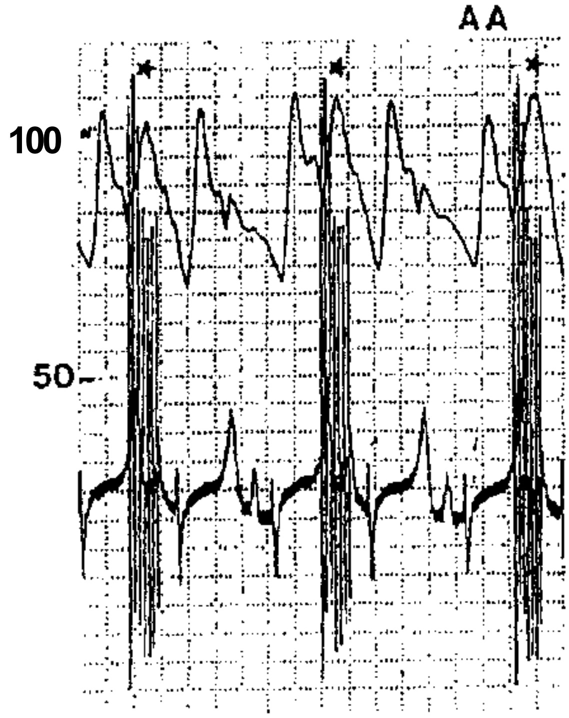

Figure 3. Diastolic augmentation in goats with latissimus dorsi contracting around an experimentally enlarged ascending aorta. (Chachques et al [8]).

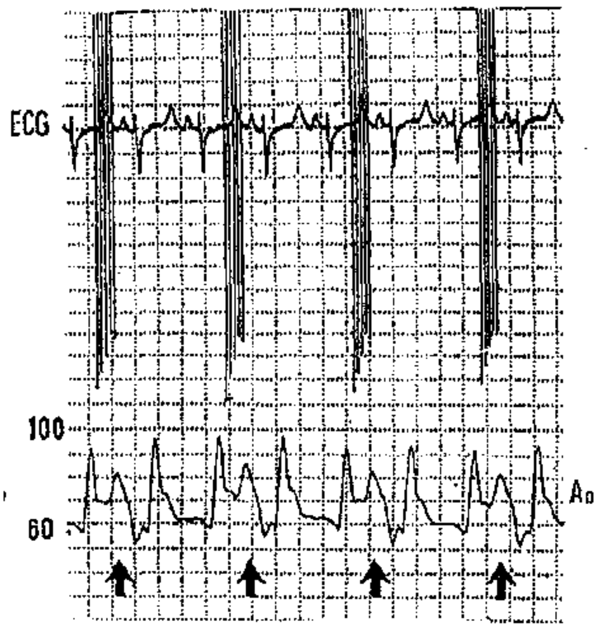

Figure 4. Diastolic augmentation in goats after inducing heart failure while the LD muscle is contracting around an enlarged ascending aorta two years after the operation (Chachques et al [10]).

Dynamic descending aortomyoplasty also revealed clear hemodynamic benefits in an animal study of Lazzara and co-workers. They demonstrated a significant increase in mean diastolic blood pressure from *62 ±4 mm* Hg to 71 ± 3 mm Hg and of the EVR (index of myocardial diastolic perfusion and ventricular oxygen demand) [30]. During this experiment heart failure was induced by rapid ventricular pacing in dogs and the procedure was monitored with the conductance catheter technique. The pressure volume loops demonstrate a shift to the left which indicates a decrease in both left ventricular end-diastolic and end-systolic volumes, as well as reduction of systolic pressures during skeletal muscle contraction (figure 5).

Apart from the chronic hemodynamic effect of LDM stimulation, also the transformation of the LDM after 12 months stimulation around the descending aorta has been reported [17]. The results showed an increased capacity for aerobic oxidation and a decreased glycolytic metabolism if compared to control LDM, all in accordance with findings from cardiomyoplasty studies. Whether muscle atrophy, fatty degeneration and fibrosis occur after chronic electrical stimulation is not extensively reported, but the 1:1 stimulation ratio of the LDM to cardiac contraction should be done with care [7]. Whereas this ratio has been abandoned in cardiomyoplasty as being to intensive [33], in conventional IABP a 1:1 ratio is still hemodynamically necessary in many situations. Even a 2:1 ratio of LDM stimulation appeared to induce muscle degeneration in a large number of animals [32]. Direct comparison of aortomyoplasty with IABP revealed comparable improvement of regional myocardial shortening in an area of acute ischemia in dogs [4]. Although the LDM muscle was stimulated chronically, the 4 week follow up period is most likely to short to exclude the possible development of muscle atrophy.

One of the main advantages while using an intra aortic balloon pump for ischemic patients is diastolic augmentation of the coronary flow. A typical example of diastolic flow augmentation in the left anterior descending coronary artery is presented from our laboratory in a dog following acute aortomyoplasty (figure 6) [2].

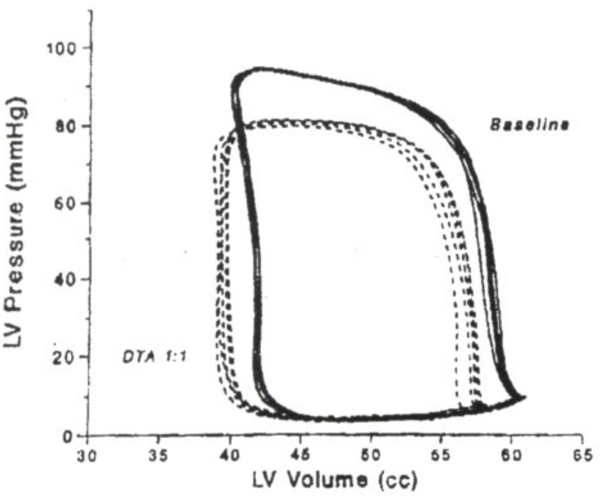

Figure 5. Pressure volume loops at baseline, and while stimulating the skeletal muscle around the descending aorta (after inducing heart failure) (Lazzara et al, [30]).

Clinical Results

The clinical experience of dynamic aortomyoplasty is very limited. Since November 1992, 14 clinical aortomyoplasty procedures have been reported worldwide in four different centers [9]. The mean age of the patients was 56 ± 7 years, 10 men and 4 women, of whom 9 had ischemic cardiomyopathy and 5 had idiopathic dilated cardiomyopathy. The mean end-diastolic left ventricular diameter was 82 ± 6 mm, the mean preoperative NYHA functional class was 3.4, and the mean left ventricular ejection fraction was only 16% ± 4%. In this group of patients the aortomyoplasty technique was either ascending aorta wrapping (n = 11) or descending aorta wrapping (n = 3) and cardiopulmonary bypass was not used in any of these cases. Hospital mortality was 14% whereas during a mean follow-up of 9 months, there was an additional 36% death rate. Although the follow-up period was only 9 months, diastolic augmentation was demonstrated, beside a significant improvement of NYHA functional class and in the quality of life. Patient evaluation at about the same follow-up duration following cardiomyoplasty revealed also improvement in NYHA association functional class, and in quality of life. More important, in these patients with dilated cardiomyopathy, reduction of ventricular dimensions were demonstrated rather than significant cardiac assist from skeletal muscle contractions [44, 45]. Possibly, NYHA class III patients with dilated cardiomyopathy are more eligible for cardiomyoplasty surgery, while class IV patients should be treated with aortomyoplasty surgery to reduce the operative risk of cardiac surgery, and to start left ventricular support within weeks after surgery.

However, it is important to notice that we are still in the beginning of the clinical evaluation (most cases were done in the last 2 years) and the number is too small to show any statistical significance neither do they indicate which patient is suitable for dynamic aortomyoplasty. Also data are insufficient to answer the question whether there is any

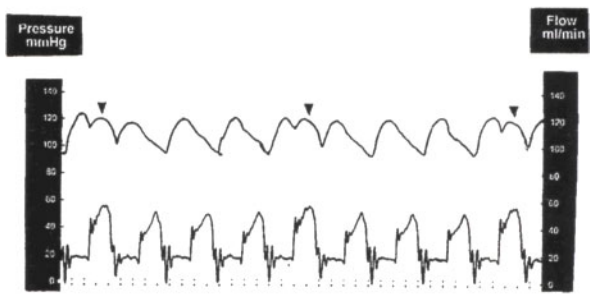

Figure 6. Diastolic augmentation of LAD blood flow during stimulation of the left latissimus dorsi around the descending aorta in a dog following acute aortomyoplasty [2].

preference for the ascending aorta over the descending aorta approach.

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