

Increasing the Length of the Latissimus Dorsi Muscle Pedicle to Enhance the Efficacy of Cardiomyoplasty

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Abstract

Objective: The efficacy of cardiomyoplasty depends upon a complete wrapping of the heart with the latissimus dorsi muscle flap (LDM). This is not possible with extremely dilated hearts. The goal of our experimental study was to increase the length of the LDM neurovascular pedicle to obtain a maximal LDM surface area and, hence, to perform a complete cardiac wrap. Three techniques were used in various combinations : a) division of the LDM tendon, b) LDM electrostimulation, c) implantation of a balloon expander behind the pedicle.

Methods: Twenty-one sheep were operated on. In group I: all animals (n = 7) had their LDM humeral tendon divided, associated in 3 of them with electrostimulation. In group II, all animals had (n = 14) a balloon tissue expander and the humeral tendon was divided. In 7 of them the LDM was electrostimulated with (n = 4) or without (n = 3) fixation of the tendon on the 3rd rib. In 7 other animals of this group the LDM was not stimulated with (n = 4) or without (n = 3) fixation of the tendon to the 3rd rib.

Results: In all groups, the pedicle was elongated. Maximal elongation was observed in group II with LDM electrostimulation: average 12.3 ± 0.61 cm versus 10.3 ± 0.15 cm in group I. LDM force decreased in all groups, but this decrease was minimized by tendon fixation and early electrostimulation. Histology of the pedicle showed well preserved structures in group I and thickening of arterial wall and nerve injury due to compression by the expander in group II.

Conclusions: A significant elongation of the neurovascular pedicle of the latissimus dorsi up to 76.3% of its original length can be obtained by the techniques used in this study. The more efficient and less deleterious technique was the division of the tendon and early stimulation of the muscle. Preservation of the LDM force was directly related to the resting muscular tension which was improved by tendon refixation and early postoperative electrostimulation.

Key words: cardiomyoplasty, Latissimus dorsi muscle, muscle-pedicle expansion.

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Cardiomyoplasty (CMP) was originally designed as a surgical treatment for patients with severe chronic heart failure refractory to medical treatment [3]. Indications include: ischemic, dysplastic, viral and all non-obstructive cardiomyopathies [6]. The principle of CMP is to assist the failing heart by chronic electrostimulation of the latissimus dorsi muscle (LDM) flap wrapped around the ventricles [1]. A synchronized burst of impulses from an implantable pacemaker allows the LDM to contract during systole, thereby augmenting cardiac ejection [17, 19]. The left LDM is usually the muscle of

choice for CMP because of its large muscular mass, its immediate proximity to the left ventricle and its ability to be transferred into the thorax while preserving its neuro-vascular pedicle [4, 10]. The power of the transposed muscle has been calculated to be 40 W/kg, which is higher than the power developed by the cardiac muscle during systolic contraction [5].

Unfortunately, a complete wrap of both ventricles by the LDM can rarely be obtained, especially in cases of extremely dilated hearts, i.e. cardiothoracic ratio greater than 0,60 and a left ventricular end-diastolic diameter

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greater than 75 mm. This is due to the limited length of the neurovascular pedicle of the LDM which makes only the distal part of the muscle suitable for the wrapping. In these cases, the wrapping of the heart is completed by using an autologous pericardial patch [8, 11] but the benefit of cardiomyoplasty is limited [15]. Another alternative is to reduce the size of the heart by a partial ventricular resection but this technique has been associated with a much higher mortality in our own experience [2]. One of us proposed the augmentation of the muscle surface area by using a balloon tissue expander (500 ml) associated with electrostimulation 2 months prior to CMP [9]. A 31% increase in LDM surface area was obtained, however the LDM fibers in direct contact with the balloon were shown to be reduced in diameter.

The aim of this experimental study was to improve the wrapping of the heart by increasing the length of the LDM neurovascular pedicle in order to obtain a larger surface area of the LDM available for this wrapping.

Materials and Methods

Twenty-one adult sheep (mean weight 28 ± 2 kg) were operated upon under general anesthesia. Induction was performed using intra-venous Propofol (8 mg/kg) and then maintained by inhaled 2% Isoflurane. All animals were placed in the right lateral decubitus position. Animals received human care in compliance with the (Guide for the Care and use of Laboratory Animals NIH publication 85-23, revised 1985).

Surgical techniques

Two techniques of pedicle elongation were evaluated: 1) Division of the LDM humeral tendon, with or without electrostimulation to allow a progressive elongation of the pedicle by muscle contraction ($n = 7$). 2) Use of a balloon expander placed posterior to the pedicle ($n = 14$). The balloon (Figure 1), was made from silicone (Euro-Silicone 12120), presented a diameter of 7 cm and a maximum inflation volume of 120 ml. The device was connected to a valved chamber allowing progressive inflation through a subcutaneous accessible port. A patch of silicone attached to the balloon was subsequently wrapped around the pedicle to protect the pedicle from adhesions. Two electrodes (Medtronic Model SP 5528 Maastricht, Netherlands) were implanted in the proximal portion of the LDM and connected to the Myostimulator (Medtronic ITREL) implanted subcutaneously.

In order to compare the different techniques of elongation, animals were assigned to the following groups:

GROUP I ($n = 7$): Divided humeral tendon.

Subgroup A ($n = 4$): without LDM electrostimulation.

Subgroup B ($n = 3$): with LDM electrostimulation.

GROUP II ($n = 14$): balloon tissue expanders:

Subgroup C ($n = 3$) without LDM electrostimulation.

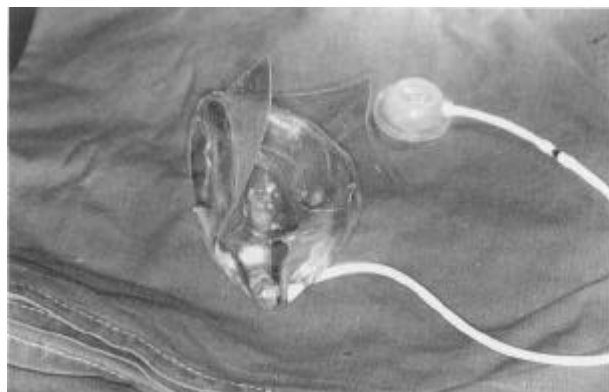


Figure 1. Balloon tissue expander. A patch of silicone attached to the balloon was subsequently wrapped around the pedicle to avoid any displacement after implantation.

Subgroup D ($n = 3$) with LDM electrostimulation.

Subgroup E ($n = 4$) with LDM electrostimulation and fixation of the tendon to the 3rd rib.

Subgroup F ($n = 4$): same as group E but without electrostimulation.

The normal, non-operated right sided LDM was used as control.

A 15 cm incision was performed from the left axilla posteriorly to the inferior tip of the left scapula to provide direct access to the LDM and its neurovascular pedicle. The dissection was performed at the proximal half of the LDM. The LDM was dissected anteriorly from the teres major muscle. The humeral tendon was divided and detached. The pedicle was identified, whenever a balloon was implanted under the pedicle and the attached silicon leaflet was fixed around the pedicle. Two intramuscular electrodes were implanted in the proximal part of the LDM. The proximal electrode (cathode) was placed near the motor nerve branches, slightly distal to their trifurcations into the muscular mass. The distal electrode was placed 3 cm distally. Electrodes were then connected to the myostimulator which was placed subcutaneously. In 8 animals (subgroup E and F), the humeral tendon was divided and secured to the posterior periosteum of the third rib just lateral to the tip of the scapula.

Postoperative filling of the tissue expander started two weeks after surgery with progressive injection of saline solution (30 cc/week) reaching a maximum capacity of 120 ml by 4 weeks. The electrostimulation protocol was started 7 ± 4 days after operation. The pulse frequency and rate of electrostimulation were gradually increased.

Target stimulation was 4 Volts, pulse width 210 microseconds and burst frequency 30 Hz, with 6 pulses per burst.

Physiological studies

At a mean of 12 ± 3 weeks post surgery, the following studies were performed on the right (control) and left LDM:

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- 1) Measurement of the pedicle length from the axillary artery to the point of penetration into the LDM.
- 2) Electrophysiologic studies of the LDM using a specific analyzer (Medtronic model 5311). Impedance and threshold of stimulation were measured. Evaluation of the LDM force by force displacement using a transducer (GRASS(r) FT10 Quincy, Massachusetts, U.S.A). The humeral tendon was fixed to the force transducer which was connected to an amplifier (Gould Model 20-4615-50, U.S.A.) and calibrated with a weight of 1500 grams. The LDM was stimulated and the measurement was recorded and compared with the weight of calibration.
- 3) Doppler flow studies of the LDM artery (Hayashi Systems Model Es-100x, Denki, Japan).

Pathological study

Before sacrifice, both LDM with their pedicle were removed from animals after injection of Heparin (2 mg/kg, I/V). Before removal of the pedicles, their lengths were measured. Both pedicles were then removed from living animals and fixed in 10% formalin. After fixation, the whole pedicle segment was cut transversely into 3 mm thick serial sections. All sections were embedded in paraffin. Three mm thick sections were obtained from each paraffin block and stained with Hematoxylin-Eosin, Masson's trichrome for collagen fibers and Orcein for elastic fibers. Histologic slides were examined under a light microscope with no knowledge of the animal groups.

After removal of the pedicles the LDMs were weighted. One specimen approximately 2 cm in diameter was taken from each LDM at the same site for histological and histochemical study. These specimens were cut into small sections. Half of these were frozen and stored at -80°C for histochemistry, and the others fixed in formalin and embedded in paraffin for histology. Histochemical studies were performed using adenosine tri-phosphatase ATPase

(pH 4,35; pH 4, 53; pH 9,4), beta-nicotinamide adenine dinucleotide, succino dehydrogenase (SDH) and alpha-glycerophosphate menadione dehydrogenase. Hematoxylin-eosine-saffran was used for histology.

Histologic slides were examined under a light microscope with no knowledge of the animal groups.

Results are expressed as mean±standard error of the mean. Analysis of variance was used to compare the animals of different groups. A p-value less than 0.05 was considered significant ($p < 0.05$).

Results

In all groups, the left pedicle length was significantly increased compared to the corresponding right one. Maximal elongation was obtained in Subgroup E (balloon + electrostimulation + tendon fixation): right (R): 6.95 ± 0.19 (control) vs left (L): 12.3 ± 0.15 cm (Table 1 and Figure 2).

The LDM force and weight were decreased in all groups with large variations shown in Table 1.

Electrophysiological studies

Electrophysiological studies showed that the stimulation threshold was significantly increased in all groups ($p < 0.05$). The maximum threshold was observed in Subgroup C (balloon without electrostimulation) L: 1.20 ± 0.28 vs R: 0.55 ± 0.07 Volts. The minimal threshold was observed in subgroup A (divided tendon without electrostimulation) L: 0.85 ± 0.05 Volts vs R: 0.8 ± 0.05 Volts. Impedance of LDM was significantly decreased in all groups ($p < 0.05$) with a maximum decrease observed in subgroup C (balloon without electrostimulation) R: 410 ± 10 vs L: 327 ± 0.7 Ohms. A minimum decrease was observed in subgroup E (balloon + electrostimulation + fixation of the tendon) R: 403 ± 60 vs L: 375.3 ± 39 Ohms (Table 2).

Doppler flow studies showed that all right thoracodorsal arteries were patent (control group). The left tho-

Table 1. Results of pedicle length, LDM force and LDM weight.

Sub groups	Pedicle length (cm)		LDM force (gm)		LDM weight (gm)	
	R	L	R	L	R	L
A: Humeral tendon divided	7.4 ± 0.15 (39.8%)	10.4 ± 0.43	1687 ± 388 (-71.1%)	485 ± 290	96 ± 21 (-25%)	72 ± 31
B: Electrostimulation	7.4 ± 0.57 (45.6%)	10.3 ± 0.61	1563 ± 269 (-56.4%)	679 ± 254	112 ± 10 (-11.6%)	99 ± 9.6
C: Balloon	7.1 ± 0.13 (56.7%)	11.1 ± 0.56	1879 ± 536 (-60.5%)	741 ± 199	75 ± 4.3 (-14.2%)	64 ± 4.1
D: Balloon+electrostimulation	6.7 ± 0.68 (76.1%)	11.8 ± 0.58	1516 ± 106 (-60.8%)	592 ± 180	104 ± 16 (-28.4%)	75 ± 28
E: Balloon+electrostimulation + fixation of the tendon	6.95 ± 0.1 (76.3%)	12.3 ± 0.15	1210 ± 120 (-46.9%)	645 ± 155	123 ± 10 (-24.6%)	93 ± 5
F: Balloon + fixation of the tendon	7.1 ± 0.29 (33.8%)	9.55 ± 0.48	2143 ± 973 (-38.4%)	1322 ± 542	101 ± 18 (-24.7%)	76 ± 16

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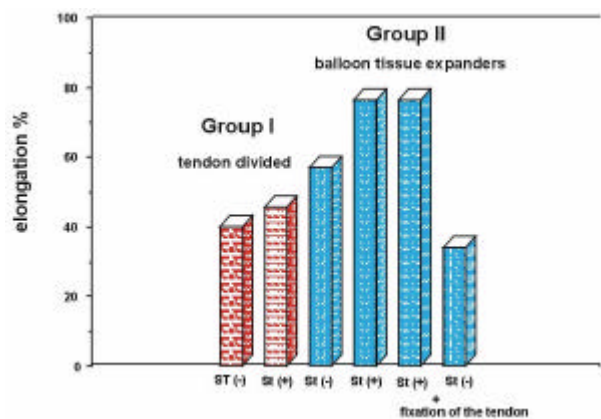


Figure 2. Elongation of the *Latissimus dorsi* muscle pedicle in all groups. ST (-) = without electrostimulation. St (+) = with electrostimulation.

raco-dorsal arteries were patent except in two animals from subgroups C and F.

Histology

All animals from group II (with balloon) displayed an arterial thickening with myointimal hyperplasia involving small and middle size arteries. Myointimal hyperplasia was composed of smooth muscle cells and a matrix of loose connective tissue. Some arteries had fragmentation of the internal elastica lumina. The media was normal in all animals but two. Arterial thickening was more important when the animals had no electrostimulation. Two animals from subgroups C and F had a sub occlusive arterial and venous thrombosis (Figure 3A).

In the same group II most nerves showed degenerative changes.

Histology of the LDM showed that all animals with a balloon had myocyte atrophy especially when they had no electrostimulation; (Figure 3B). In contrast, animals with no balloon had no or little atrophy. The transformation of the LDM fibers into fatigue resistant fibers

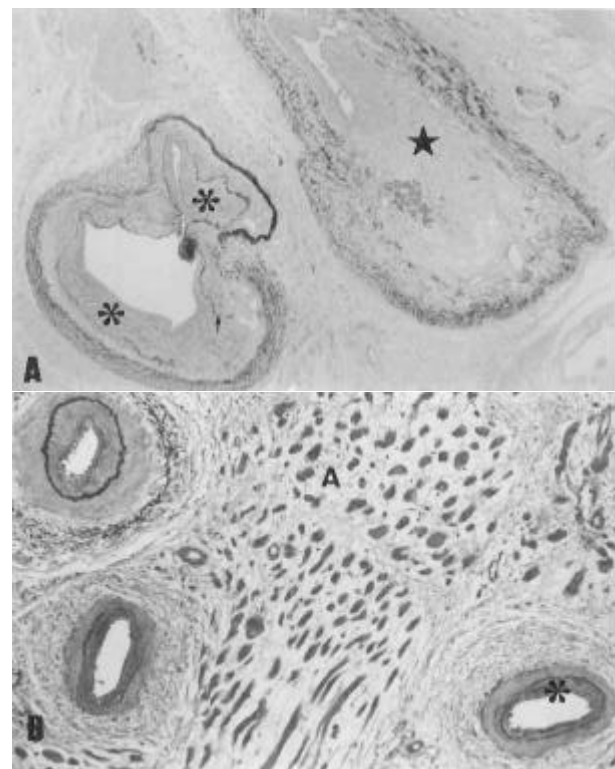


Figure 3. Pedicle with balloon and no electrostimulation. A: Vein thrombosis (★) and important myointimal hyperplasia (*). B: myocyte atrophy (A) and myointimal hyperplasia (*) (Hematein-eosin stain, A: X 100; B: X 40).

oxidative fibers) was complete in subgroup B (divided tendon + electrostimulation) (Figure 4A). In subgroup E there was a majority of oxidative fibers type I (slow-twitch oxidative fatigue-resistant fibers). The fixation of the tendon to the third rib and an early electrostimulation program improved this transformation. (Figure 4B). No recent or healed infarctions were observed.

Table 2. Results of electrophysiological studies of the *Latissimus dorsi* muscle.

Sub groups	Threshold (Volt)		Impedance (Ohm)	
	Right	Left	Right	Left
A: Humeral tendon divided	0.80±0.05 (6.25%)	0.85±0.05	516±14 (-18.7%)	419±56
B: Electrostimulation	0.76±0.05 (18.4%)	0.90±0.50	421±12 (-12.8%)	376±45
C: Balloon	0.55±0.07 (118.18%)	1.20±0.28	410±10 (-20.2%)	327±0.7
D: Balloon + Electrostimulation	0.80±0.05 (81.25%)	1.45±0.77	565±45 (-17.7%)	465±18
E: Balloon + electrostimulation + fixation of the tendon	0.80±0.05 (62.5%)	1.30±0.17	403±60 (-6.9%)	375±39
F: Balloon + fixation of the tendon	0.80±0.05 (41.2%)	3.40±0.14	412±38 (-12%)	363±25

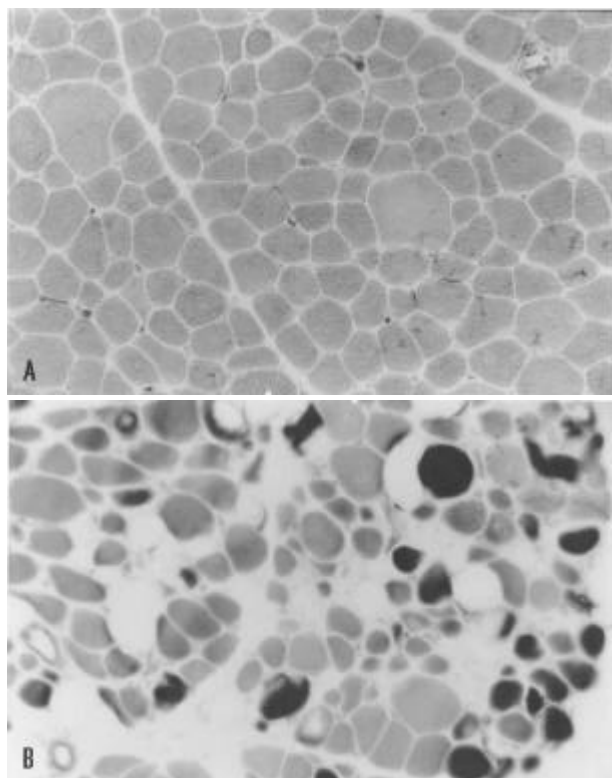


Figure 4. Histochemical studies of the latissimus dorsi muscle stimulated by pulse trains for 8 weeks. The lightly stained fibers are classified as type I, slow-twitch oxidative fatigue-resistant fibers, and the darkly-stained fibers are type II, fast-twitch glycolytic fatiguable fibers. A: group I (without balloon) complete conversion from type II glycolytic to type I oxidative. B: In group II (with balloon) there is a majority of oxidative fibers type I [ATPase stain (pH 9,4) X 322].

Discussion

The LDM has been used in plastic surgery for its large surface area and its well characterized neurovascular pedicle [20]. For the same reasons the LDM was selected for the CMP technique to cover the failing heart [3, 6]. A complete myocardial wrap provides maximal cardiac assistance [14] but this is rarely encountered clinically because of the discrepancy between the LDM flap surface area and the dilated heart. In our study, the use of a tissue expander inflated to a capacity of 120 ml with saline solution increased the LDM pedicle to a maximum length of 76%.

Expansion and elongation of tissues are frequently used in plastic surgery and orthopedics [12, 13, 16, 17, 18]. We have adapted this principle with some technical modifications in order to increase the length of the neurovascular pedicle of the LDM. However, whenever using a balloon expander in contact with the pedicle a foreign body reaction occurred which led to the development of fibrosis around the pedicle. The thoraco-dorsal artery

showed arterial wall thickening which was absent when no balloon was used. The thickening of the arterial wall was more important in subgroups without electrostimulation compared to subgroups with electrostimulation. This may be due to an increased arterial flow in stimulated muscle. Nerve injury was observed in all balloon subgroups probably due to compression and fibrosis.

In the group without balloon expander the maximal elongation was obtained by dividing the humeral tendon of the LDM and electrostimulation of the muscle. The increase of the length of the pedicle was less than in the previous groups, but there was no lesion of the neurovascular pedicle. The force of contraction of the LDM decreased however because of the loss of muscle tension. Securing the tendon to the third rib (subgroup E and F) obviates this inconvenience.

In these experiments chronic electrostimulation had two goals: 1) Enhancing elongation when the tendon was divided. 2) Transforming the muscle fibers from fast twitch type II (easily fatiguable) to slow twitch type I (fatigue resistant fibers). The muscular force of the LDM was better preserved when the electrostimulation program started 3 days after the operation, probably because electrostimulation restores a more physiological tension of the muscular fibers.

Conclusions

The division of the tendon of the LDM associated with electrostimulation provided a 45.6% elongation of the neurovascular pedicle and therefore a better covering of the heart by the muscle flap. The use of balloon expanders provided a better elongation up to 76,3% with however significant nerve injury and wall thickening. The immediate loss of the LDM force due to the distension of the muscular fibers was minimized by fixation of the tendon and early electrostimulation. This study may bring an important contribution to the clinical use of CMP particularly in patients with hearts too large to be fully covered by a LDM flap.

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