Electrical Stimulation For Cardiac Assistance


Abstract: OBJECTIVES: This study evaluates the hypothesis that in patients with syncope of unknown origin and heart anomalies, inducible ventricular arrhythmias are specific arrhythmias and therefore should be treated as such. BACKGROUND: Although syncope is a frequent clinical entity, the evaluation and treatment of patients with syncope without a clear etiology still remains undefined. Many patients with syncope of undetermined origin undergo invasive electrophysiologic evaluation. Abnormalities of the sinus node, prolongation of conduction times or inducible arrhythmias found during these evaluations are usually assumed to be the cause of syncope, and are consequently treated. However, whether tachyarrhythmias are truly the cause of syncope, and whether treatment of these tachyarrhythmias can prevent recurrent syncope and arrhythmic death, is unknown. PATIENTS AND METHODS: An electrophysiological study was performed on 160 patients with structural heart disease and syncope of unknown origin. In 23 out of the 160 patients (16%), programmed electrical stimulation induced sustained ventricular arrhythmias. In 18 out of the 23 patients an automatic defibrillator was implanted and they form the study group. RESULTS: In these 18 patients, programmed ventricular stimulation induced sustained monomorphic ventricular tachycardia in 12, sustained polymorphic ventricular tachycardia in 2 and ventricular fibrillation in 4. During a mean follow-up of 14 months, 9 patients received 81 appropriate therapies from the device (53 because of ventricular tachycardia and 23 because of ventricular fibrillation). The probability of appropriate therapy was 100% at 1 year follow-up. There were no episodes of sudden death and 1 patient died of congestive heart failure. CONCLUSIONS: In patients with syncope of undetermined origin, heart disease and inducible ventricular tachyarrhythmias treated with a implantable cardioverter defibrillator, there is a high incidence of appropriate therapies. Our results support the practice of using implantable cardioverter defibrillators in patients with syncope of unknown origin, heart disease and inducible ventricular arrhythmias


Abstract: BACKGROUND: Dynamic cardiomyoplasty has shown promise as a surgical treatment for congestive heart failure, however, skeletal muscle damage has been reported in the latissimus dorsi muscle flap. Possible etiologies for the muscle damage include surgical dissection of the latissimus dorsi muscle with interruption of collateral blood supply, as well as chronic electrical stimulation of the muscle. METHODS: To investigate these possible etiologies, we conducted a series of experiments using the goat model, evaluating blood flow and muscle morphology.
following surgical dissection and chronic stimulation of the latissimus dorsi muscle. Four different conditions were evaluated: (1) latissimus dorsi muscle that was neither dissected nor chronically stimulated; (2) latissimus dorsi muscle that was stimulated, but not dissected; (3) latissimus dorsi muscle that was surgically dissected, but not chronically stimulated; and (4) latissimus dorsi muscle that was both surgically dissected and chronically stimulated. CONCLUSION: We concluded that skeletal muscle damage resulted primarily from the surgical dissection, whereby the collateral blood supply to the latissimus dorsi muscle was interrupted and not primarily as a result of chronic electrical stimulation


Abstract: BACKGROUND: Aortic counterpulsation, either biologic or mechanical, is a useful technique to support circulation during left ventricular dysfunction. METHODS: In this study we used an induced cardiac failure model in acute open chest sheep to compare hemodynamic improvements between thoracic and abdominal aortic counterpulsation. This was achieved with left latissimus dorsi and left hemidiaphragm muscle flaps. RESULTS: Thoracic and abdominal aortic counterpulsation in heart failure resulted in a significant improvement of hemodynamic parameters. Subendocardial viability index, defined as diastolic pressure-time index to systolic tension-time index, in thoracic and abdominal aortomyoplasty showed significant improvement (p<0.05) when cardiac assistance was performed by electrical stimulation of each muscle flap. A new counterpulsation index derived from diastolic and systolic areas beneath the aortic pressure curve was tested, obtaining a correlation coefficient with the subendocardial viability index of 0.758 (p<0.001). Values of subendocardial viability index and counterpulsation index showed minimal variability. CONCLUSIONS: Treatment of experimentally induced cardiac failure with dynamic abdominal aortic counterpulsation allows an effective hemodynamic improvement in open chest sheep. Furthermore, this diastolic arterial pressure augmentation could be evaluated through a new counterpulsation index derived from diastolic and systolic areas beneath the aortic pressure curve


muscle ventricle. ASAIO J. 41, M499-M507.
Abstract: Some patients with pre end-stage congestive heart disease do not receive a significant hemodynamic benefit from dynamic cardiomyoplasty because, during prolonged preoperative immobilization, their latissimus dorsi muscle (LDM) becomes extremely weak. It is the authors' hypothesis that the local administration of an anabolic steroid into an electrically stimulated LDM will produce a thicker and stronger muscle with significant resistance to fatigue. The electrical stimulation training protocol of sheep continued for 8 weeks. For localized anabolic steroid administration an osmotic pump was placed in a subcutaneous pocket and the catheter was introduced into the LDM. The contractile force of electrically stimulated and unstimulated control muscle was studied. Control data were calculated as 100% and all other data were corrected to control. After 4 weeks there was no decrease in contractile force. The change seen was from 88 to 100% with different preloads (10, 15, and 20 g/kg) and amplitudes of impulses (5 and 10 V). After 8 weeks, the LDM was more powerful than before electrical stimulation, with a change of 97-133%. Usually after 8 weeks of electrical stimulation alone, contractile force decreases to 70-75%. During a fatigue test (30 min, 100 bursts per minute, 10-25 Hz, ripple frequency, 10 V impulse amplitude) after 4 and 8 weeks of our protocol, the LDM lost only 12% of its initial force, whereas control muscle lost 40%. Thus local anabolic steroid administration makes the LDM stronger and more useful for cardiomyoplasty.

Abstract: Six adult sheep and four newborn lambs (5 days old) were implanted with stimulator leads into the latissimus dorsi muscle and connected to a Myostim 7220 pacing system (Telectronics Pacing Systems, Inc., Englewood, CO). Electrical stimulation was started immediately after the operation. After 8 weeks of electrical stimulation, contractile force (CF) in adult sheep decreased to 76-81%, and to 78-82% in lambs. After 2 weeks' delay, CF in adults was 96-98%, and only 89-93% in lambs. After a 30 min intensive stress test, unconditioned control muscle lost 39% in lambs and 43% in adults. Muscle conditioned for 8 weeks lost 7-8% CF. However, after 2 weeks' delay, CF in adult muscle lost 33%, but only 12% in lambs. After cessation of electrical stimulation, the LDH-5 and LDH-1 + 2 fractions reverted to initial levels in adults, whereas in lambs, these levels continued to follow trends established during electrical stimulation. In both adults and lambs, the percent area occupied by the mitochondria increased during electrical stimulation by 6.9% in adults and 6.5% in lambs. After electrical stimulation cessation, the percent area in adults returned to baseline levels, whereas it continued to be elevated in lambs (3.3% vs 5.1%, respectively). The transformed muscle of the lamb did not revert to baseline levels after a delay period.


Abstract: The hemodynamic effects of cardiomyoplasty (CMP) have been
investigated in many centers, but the question of whether it is necessary to stimulate the latissimus dorsi muscle (LDM) 24 hours a day has not been answered. The main goal of our investigation was to determine whether hemodynamic results after CMP were impaired when continuous electrical stimulation (ES) was off for 12 hours a day. A model of chronic heart failure was created in 12 sheep by performing an arteriovenous anastomosis and administering doxorubicin. Two weeks after the anastomosis, CMP was performed in eight sheep (experimental series); ES training was begun at 2 weeks after CMP. After completion of the initial ES conditioning (8 weeks after CMP), one group of sheep continued to receive ES 24 hours daily. Another group of sheep had only 12 hours of ES daily. Hemodynamic parameters were investigated 2 weeks later with the stimulator turned on and then off. With doxorubicin administration, arteriovenous anastomosis created a stable model of biventricular heart failure (right atrial pressure 20 +/- 3 mmHg vs 6 +/- 2 mmHg at baseline; pulmonary capillary wedge pressure 18 +/- 3 mmHg vs 9 +/- 2 mmHg; left ventricular end-diastolic area 15.2 +/- 1.2 cm2 vs 6.4 +/- 0.7 cm2; left ventricular ejection fraction 0.38 +/- 0.6 vs 0.65 +/- 0.7). Cardiomyoplasty improved hemodynamic status in all eight experimental sheep. However, when the investigation was performed with the stimulator off, this improvement was statistically insignificant. With stimulation on, there was decreased right atrial pressure, pulmonary capillary wedge pressure, left ventricular end-diastolic volume, and increased left ventricular ejection fraction. With the stimulator turned off for 12 hours daily, hemodynamic measurements did not differ from data with continuous ES for 24 hours daily. Because hemodynamic results do not seem to be impaired, we recommend daily, periodic cessation of stimulation to prevent damage to the LDM after CMP.


Abstract: Dynamic cardiomyoplasty (DCM) is an emerging surgical procedure for heart failure in which the patient's latissimus dorsi (LD) muscle is wrapped around the heart and stimulated to contract in synchrony with the heartbeat as a cardiac assist measure. A 6 week training protocol of progressive electrical stimulation renders the normally fatigueable skeletal muscle fatigue-resistant and suitable for chronic stimulation. To date, over 500 procedures have been performed in worldwide clinical trials. Investigators typically report symptomatic improvement and modest hemodynamic improvement in patients. Controversy exists regarding the exact mechanism of DCM. To test the hypothesis that DCM augments cardiac stroke volume through improvement in systolic function, we formulated an engineering model of dynamic cardiomyoplasty to predict stroke volume. The heart and the LD were modeled as nested (series) elastance chambers, and the vasculature was represented by a two-element Windkessel model. Using five healthy goats, we verified model predictions of stroke volume for both stimulator ON beats (y = 1.00x - 0.08, r = 0.87, p < 0.0001) and OFF beats (y = 1.01x + 1.06, r = 0.91, p < 0.0001), where x and y are the measured and predicted stroke volumes, respectively. The model confirms that using untrained latissimus dorsi applied to the normal myocardium produces only moderate increases in stroke volume and suggests that future research should focus on increasing LD strength after training.

Abstract: BACKGROUND: We hypothesized that diastolic counter-pulsation using aortomyoplasty will increase coronary blood flow. METHODS: In dogs (n = 6, 20 to 25 kg), the left latissimus dorsi muscle was isolated, wrapped around the descending thoracic aorta, and conditioned by chronic electrical stimulation. Heart failure was induced by rapid ventricular pacing. In a terminal study, left ventricular and aortic pressures, and blood flow in the left anterior descending coronary artery and descending aorta were measured. The endocardial-viability ratio was calculated.

RESULTS: Aortomyoplasty increased mean diastolic aortic pressure (70 +/- 5 to 75 +/- 5 mm Hg, p < 0.05) and reduced peak left ventricular pressure (86 +/- 4 to 84 +/- 4 mm Hg, p < 0.05), leading to a 16% increase in endocardial-viability ratio (1.29 +/- 0.05 to 1.49 +/- 0.05, p < 0.05). Coronary blood flow was increased by 15% (8.2 +/- 1.5 to 9.4 +/- 1.6 mL/min, p < 0.05). During muscle contraction, 2.7 +/- 0.5 mL was ejected from the wrapped aortic segment. CONCLUSIONS: These data demonstrate that aortomyoplasty provides successful diastolic counterpulsation after muscle conditioning and heart failure.


Abstract: Cardiomyoplasty, a new therapy for heart failure, uses autologous skeletal muscle to mechanically assist the heart. The success of dynamic cardiomyoplasty is critically dependent on the contraction strength of the assisting skeletal muscle. Unlike cardiac muscle, skeletal muscle contracts in a graded response to electrical stimulation. However, in current cardiomyoplasty practice, no systematic technique exists to set the stimulating voltage effecting skeletal muscle contraction. The stimulating voltage is simply set to some multiple of the "threshold" voltage. Furthermore, researchers do not consider the role of stimulating voltage when they determine the amount of assistance afforded during cardiomyoplasty. To more accurately assess the value of this heuristic voltage-setting technique, we investigated the role of stimulating voltage on the strength of contraction of the latissimus dorsi muscle. Six New Zealand white rabbits had isovolumic hydraulic pouches constructed from the latissimus dorsi muscle. The muscles were wrapped around a compliant balloon in which isovolumic pressure development was measured during tetany-inducing burst (pulse-train) stimulation. The tetanic plateau of the pouch pressure record was used to measure the effects of stimulating voltage on skeletal muscle contraction. Results indicated that (1) increasing stimulating voltage from two to four times the "threshold" voltage increased normalized pouch pressure from 0.38 +/- 0.21 to 0.78 +/- 0.12 (mean +/- SD) (p < 0.05); (2) the threshold-normalized voltage necessary to cause maximal muscle contraction varied widely (5.7 +/- 2.0, mean +/- SD; range, 3.1 to 9.3); and (3) the current achieving maximal pressure development varied from 5.6 to 31.4 mA (19.9 +/- 10.4 mA). (ABSTRACT TRUNCATED AT 250 WORDS)

Abstract: OBJECTIVE: The chronic shortage of donor organs for cardiac transplantation and the high costs for mechanical assist devices demand the development of alternative cardiac assist devices for the treatment of severe heart failure. Cardiac assistance by stimulated skeletal muscles is currently investigated as such a possible alternative. The goal of the presented study was to construct a newly designed biological skeletal muscle ventricle and to evaluate its possible hemodynamic efficacy in an acute sheep model. METHODS: A total of 14 adult sheep were used for acute experiments. The entire thoracic aorta including the aortic root was excised from a donor sheep. An aorto-pericardial pouch conduit (APPC) was created by enlarging the aortic circumference in its middle section with two strips of pericardium. This biological conduit was anastomosed in parallel to the descending aorta of a recipient sheep, using the aortic root as an inflow valve to the conduit. Stimulation electrodes were applied to the thoracodorsal nerve and the latissimus dorsi muscle was detached from the trunk and wrapped around the pouch. ECG-triggered functional electrical stimulation was applied during cardiac diastole to simulate aortic counterpulsation. Stimulation was performed during various hemodynamic conditions. RESULTS: A standardised surgical procedure suitable for long term studies was established during six experiments. An APPC, with 70-80 mm filling volume, was found to be of optimal size. In another eight experiments, hemodynamic measurements were performed. Under stable hemodynamic conditions the stimulation of the biological skeletal muscle ventricle induced a significant increase of mean arterial pressure by 14% and mean diastolic pressure by 26%. During pharmacologically induced periods of cardiac failure, the stimulation of the APPC increased mean arterial pressure by 13% and mean diastolic pressure by 19%. In all eight experiments, the diastolic peak pressure reached supra-systolic values during stimulation. CONCLUSIONS: The results demonstrate the hemodynamic efficacy of this newly designed biological skeletal muscle ventricle as an aortic counterpulsation device. Chronic experiments using a preconditioned fatigue-resistant muscle will further help to evaluate its possible clinical significance.


Abstract: Dynamic myoplasty combines muscle transfer with electrical stimulation to provide contractile function that augments or replaces impaired organ function. Dynamic cardiomyoplasty was the first clinical application in which a skeletal muscle, latissimus dorsi, was transferred and stimulated to provide cardiac assistance, a function different from its original one. The problem of early muscle fatigue that was encountered in the initial implementation of the method was solved by training the muscle with electrical stimulation and thus changing its fiber composition. With intramuscular electrodes, the conditioned latissimus dorsi is stimulated in synchrony with the heart muscle. Safeguards are built into the two-channel implanted stimulator to avoid excessively high pulse rates. Clinicians report that 80% of patients with moderate to severe heart failure prior to operation showed a clinical improvement of 1.6 New York Heart Association classes. Alternative methods of providing cardiac assistance that are also being investigated include wrapping the muscle around the aorta, creating a skeletal muscle ventricle, and using the muscle to power an
implantable pump. These latter techniques are still under preclinical investigation. Compared with heart transplant, cardiomyoplasty has the great advantage of not being subject to tissue rejection. The second principal application of dynamic myoplasty is treatment of fecal incontinence through creation of an electrically stimulated skeletal muscle neosphincter (ESMNS). The gracilis muscle of the leg is mobilized, wrapped around the anal canal, and conditioned with electrical stimulation to become more fatigue resistant. To achieve continence, the muscle is continuously stimulated except when the patient wishes to defecate. Overall success rates in achieving continence are 60-65%. Both cardiomyoplasty and the ESMNS technique, and their associated devices, are being refined through ongoing clinical trials.


Hakami A., Santamore W.P., Stremel R.W., Tobin G., and Hjortdal V.E. (1999) Evaluation of stimulation parameters on aortomyoplasty, using Latissimus Dorsi muscle in a goat model: an acute study. Eur. J. Cardiothorac. Surg. 16, 228-232. Abstract: OBJECTIVE: Dynamic aortomyoplasty using Latissimus Dorsi muscle (LDM) has been shown to improve myocardial function. However, systematic examination of the effects of stimulation parameters on aortic wrap function has not been done. Thus, the present study measures the direct effect of stimulation voltage, pulse train duration, frequency of the pulses, and the duration of the stimulation delay from R wave on the aortic wrap function. METHODS: In eight female goats, the left LDM was wrapped around the descending aorta. The muscle was then subjected to electrical stimulation, altering frequency of stimulation pulses (16.6, 20, 25, 33 and 50 Hz), amplitude (2, 4, 6, 8 and 10 V), and number of pulses (2, 4, 6, 8 and 10 pulses) in a train stimulation. Left ventricular, aortic pressure, and pressure generated by LDM on aorta (wrap pressure) was measured. The changes in hemodynamic parameters mentioned above were calculated and compared for different stimulation parameters during unassisted and assisted cardiac cycles. RESULTS: Aortomyoplasty counterpulsation using LDM provided significant improvement in wrap pressure (78 mmHg +/- 2), aortic diastolic pressure, and changes in aortic diastolic pressure from 2 to 4 V (P < 0.05). Further increase in amplitude did not make any significant improvements of the above mentioned parameters. Significant augmentation of wrap pressure (82 mmHg +/- 2), aortic diastolic pressure (79 mmHg +/- 3) and changes in aortic diastolic pressure (12 mmHg +/- 1) occurred at 6 pulses (P < 0.05). Other changes in number of pulses did not show any significant improvements. Significant improvement of wrap pressure (80 mmHg +/- 2), aortic diastolic pressure (73 mmHg +/- 3) and changes in aortic diastolic pressure (12 mmHg +/- 1) was observed with a frequency of 33 Hz. To examine a wide range of delays from the onset of the QRS complex to LDM stimulation, stimulation was delivered randomly. The exact delay was determined from the ECG signal and superimposed LDM stimulation pulses. CONCLUSIONS: In this study we present a new measurement, wrap pressure. We also present that in aortomyoplasty using LDM, the most significant improvement in wrap pressure, aortic diastolic pressure and changes in aortic diastolic pressure occurs when the
stimulation consists of an amplitude of 4 V, a frequency of 33 Hz and a train stimulation of 6 pulses

Abstract: Whole muscle contractile characteristics and fatigue resistance were studied in male patients with chronic heart failure (n = 6) and in healthy control subjects (n = 6). Maximum voluntary isometric strength in the major muscle groups of leg (plantar flexors and knee extensors) and arm (elbow extensors and elbow flexors), was found to be similar for both groups of subjects. However, a faster isometric twitch time course was observed in the plantar flexor and knee extensor muscles of heart failure chronic patients. The poor resistance to fatigue in the knee extensors of chronic heart failure patients was confirmed in the present study, but using twitch interpolation this was shown not to be due to poor activation. The plantar flexors of chronic heart failure patients also showed a tendency to be less resistant to fatigue, even when the muscle was activated by direct electrical stimulation. The present study shows that independent of muscle strength, patients with chronic heart failure may possess muscles that are faster to contract and less resistant to fatigue. However, it seems this increased fatigability is not due to poor muscle activation

Abstract: INTRODUCTION AND OBJECTIVES. The purpose of this study is to show our experience in clinical dynamic cardiomyoplasty. PATIENTS, MATERIALS AND METHODS. Six patients with end-stage heart failure and 2 patients with left ventricular aneurysm underwent dynamic cardiomyoplasty using the latissimus dorsi muscle. The latissimus dorsi was electrically conditioned before the procedure through a lead placed under local anesthesia and connected to an external cardiac pace-maker. Surgical technique--including dissection of the latissimus dorsi and encircling of the ventricles with the muscle flap--was performed in general terms as described at the Broussais Hospital. In the first 3 patients a bipolar lead connected to a single impulse generator was used. In the other 5 patients a train of impulses cardiomyostimulator was used. Changes in systolic function were studied through Doppler- echocardiography and radionuclide studies. Changes in diastolic function were evaluated through E wave velocity and deceleration time. RESULTS. Mean follow up was 9 +/- 5.7 months. No early deaths were recorded. One patient underwent emergency surgery, one week after the procedure, because of a tear of the patch used to close the wall defect after left ventricular aneurysm resection. In 2 patients a subcutaneous serous collection secondary to muscle dissection was evacuated. One patient died due to a stroke 4 months after the procedure. Another patient died after an unsuccessful coronary transluminal percutaneous angioplasty 11 months after the procedure. An improved functional class was observed in all patients. No changes in systolic function were observed after surgery when the cardiomyoestimulator was turned-off either with echocardiography (26.7 +/- 8.6 vs 24.8 +/- 5.8% [NS]) or radionuclides (24.5 +/- 9.5 vs 20.2 +/- 8.3% [NS]). When the cardiomyostimulator was turned-on a statistically significant increase of the left ventricular ejection fraction was observed either with echocardiography (24.8 +/- 5.8 vs 37 +/- 10.3%; p < 0.05) or radionuclides (20.2 +/- 8.3 vs 33.3 +/- 12.2%; p < 0.05). This significant increase of the ejection fraction has been observed in subsequent
studies. Nevertheless the differences when the cardiomyostimulator is turned-on and turned-off have decreased several months after the procedure. A significant increase of the left ventricular outflow velocity (cm/sec) was observed when the generator was turned-on (57.7 +/- 20.4 vs 75.1 +/- 17.8%; p < 0.01). A significant increase of the dP/dt (mmHg/sec) was observed when the generator was turned-on (706.3 +/- 291.5 vs 592.6 +/- 181.6%; [NS]). No significant changes were observed on E wave velocity. A significant decrease of the deceleration time was observed several months after the procedure (p < 0.05).

CONCLUSIONS. We believe that dynamic cardiomyoplasty is a safe and valid surgical procedure for some patients with end stage cardiomyopathies as well as in association with Jatene's technique for the management of left ventricular aneurysms. An improvement in functional class is present and a significant increase of the left ventricular systolic function. Nevertheless it is necessary to find new systolic parameters, independent of volumetric calculations, to evaluate the mechanical support of the muscle as well as to determine the long-term pattern of electrical stimulation.


Abstract: During the last decade dynamic cardiomyoplasty has been introduced as a new method to treat patients with severe heart failure. This procedure consists of the wrapping of the latissimus dorsi (LD) muscle around the heart with electrical stimulation of the muscle synchronous to cardiac contraction. The optimal pacing mode of the muscle, during the conditioning and working period of the LD muscle, is still unclear. The pace protocol, currently used worldwide, has a maximal number of muscle tetanic contractions of 100 per minute. Data are presented on the LD muscle contraction characteristics using that protocol. Both force measurements from six in situ stimulated goat LD muscles and x-ray evaluation of the movement of metallic clips on wrapped LD muscles in two patients were used. Results demonstrate that LD muscle force is well maintained at the maximal rate of 100 contractions per minute but relaxation is severely hampered. This may lead to diminished support of the failing heart and damage of the wrapped muscle. A pacing protocol is proposed using a lower maximal stimulation rate


Abstract: OBJECTIVES. To obtain information on the long-term effects of dynamic cardiomyoplasty on hemodynamics and muscle histology, this surgical method was evaluated in goats. BACKGROUND. Dynamic cardiomyoplasty has been introduced as a new method to treat patients with severe cardiac failure. METHODS. In 24 goats, the left latissimus dorsi muscle was wrapped around the heart. The muscle was then subjected to progressive electrical stimulation. In 16 goats, invasive transesophageal Doppler echocardiographic measurements and histologic
evaluation of the latissimus dorsi muscle were performed at $\geq 12$ weeks after the wrapping. RESULTS. Only two goats showed an increase in aortic and left and right ventricular pressures concomitant with increased aortic flow during latissimus dorsi muscle stimulation both before and after induction of cardiac failure using imipramine. This was accompanied by a preserved latissimus dorsi muscle structure and nearly complete transformation to type I muscle fibers. The remaining 14 goats showed extensive lipomatosis in the latissimus dorsi muscle, with severe intimal hyperplasia and proliferation of smooth muscle cells in the walls of the thoracodorsal artery and its branches. An increase in endoneural and endomysial connective tissue was observed, with some goats showing destroyed nerve branches near the electrodes. These findings differed from those observed after long-term electrical stimulation of goat latissimus dorsi muscle in situ. CONCLUSIONS. Dynamic cardiomyoplasty is of use in the treatment of severe heart failure if the histologic structure of the wrapped latissimus dorsi muscle remains intact. Long-term results in goats suggest that the current approach used in dynamic cardiomyoplasty may lead to deterioration of the wrapped muscle.

Ma Y.G., Wang D.M., Li J.N., and Zhu H.Y. (1994) Cardiac function and histological changes after non-dynamic cardiomyoplasty and preliminary study of dynamic cardiomyoplasty. Chin Med. J. (Engl.) 107, 836-839. Abstract: By means of histological method and ultrasound cardiographic (UCG) examination, the left-right ratio of transectional area of muscle fiber of latissimus dorsi muscle (LDM) after non-dynamic cardiomyoplasty was 77.4 +/- 11.7% in Group I (3 weeks after operation), and 78.4 +/- 11.6% atrophy and hyperplasia of LDM, but the basic structure was retained. The ejection fraction (EF) decreased significantly after operation (P < 0.05), but the difference between two groups was non-significant. Also, dynamic cardiomyoplasty was performed on a sheep. UCG showed the increased cardiac systolic function after operation. ATPase, succinodihydrogenase (SDH) and PAS examination implied the strengthening of fatigue-resistant ability in skeletal muscles after long-term electrical stimulation. So cardiomyoplasty is suggested to be a supplementary measure in treating end-stage heart failure.

Maillefert J.F., Eicher J.C., Walker P., Dulieu V., Rouhier-Marcer I., Branly F., Cohen M., Brunotte F., Wolf J.E., Casillas J.M., and Didier J.P. (1998) Effects of low-frequency electrical stimulation of quadriceps and calf muscles in patients with chronic heart failure. J. Cardiopulm. Rehabil. 18, 277-282. Abstract: PURPOSE: The aim of this preliminary study was to evaluate the effects of low-frequency electrical stimulation of quadriceps and calf muscles on global exercise capacities, skeletal muscle metabolism, calf muscle volume, and cardiac output in patients with chronic heart failure. METHODS: Fourteen patients with chronic heart failure (mean age of 56.4 years +/- 9.1 SD; mean radionuclide left ventricular ejection fraction of 22.3% +/- 8.8 SD) underwent 5 weeks (1 hour per day, 5 days per week) of low-frequency electrical stimulation of quadriceps and calf muscles. RESULTS: Low-frequency electrical stimulation was well tolerated. Exercise capacity and the calf muscles volumes increased significantly after rehabilitation in comparison with prior rehabilitation (the peak oxygen consumption increased from 17.2 mL/(kgmin) +/- 5.3 SD to 19.6 mL/(kgmin) +/- 5.9 SD; the anaerobic threshold increased from 12.3 mL/(kgmin) +/- 3.2 SD to 15.2 mL/(kgmin) +/- 3.3 SD; the 6-minute walking test increased from 419 m +/- 122 SD to 459 m +/- 114.3 SD; the gastrocnemius volume increased from 259.4 cm3 +/- 58 SD to 273.4
cm3 +/- 74 SD, and the soleus volume increased from 319 cm3 +/- 42.9 SD to 338 cm3 +/- 52.5 SD). The New York Heart Association class was improved after rehabilitation. The P-31 nuclear magnetic resonance spectroscopy of gastrocnemius muscle data were not significantly modified after rehabilitation, thereby inferring that no significant improvement of the muscle metabolism occurred. These data reinforce the hypothesis of an increased muscle mass during stimulation. It is noteworthy that the electrical stimulation did not increase cardiac output at any stage; an enormous asset in favor of this mode of rehabilitation. CONCLUSION: These results suggest that low-frequency muscular electrical stimulation is well tolerated, induces an increased exercise capacity in patients with chronic heart failure, without an undesirable increase in cardiac output.

Malek A.M. and Mark R.G. (1989) Functional electrical stimulation of the latissimus dorsi muscle for use in cardiac assist. IEEE Trans. Biomed. Eng 36, 781-788. Abstract: Direct and nondirect nerve stimulation modes of the thoraco-dorsal nerve (TDN) leading to the latissimus dorsi muscle (LDM) were evaluated by using nerve cuff electrodes (NCE) and intramuscular electrodes (IME), respectively. Following electrode implantation, the LDM was chronically stimulated for two months to induce muscle transformation to oxidative, fatigue-resistant type I muscle fibers. Threshold and impedance values were measured regularly to establish the stability of the implants. The LDM was then dissected, shaped into a ventricle, subjected to a hydraulic load and stimulated using a controlled-voltage pulse-train stimulator with adjustable parameters. Electrical input and hydraulic output variables were measured to obtain the recruitment characteristics and to compare the efficiency of the two types of electrodes. Results indicate a tradeoff between the NCE’s lower threshold, higher recruitment, and lower energy consumption at saturation, and the IME’s greater mechanical stability and better long-term reproducibility.


Odim J.N., Li C., Desrosiers C., Chiu R.C., O’Brien P.J., Hamilton N., and Ianuzzo C.D. (1991) The remodelling of skeletal muscle for indefatigable hemodynamic work. Can. J. Physiol Pharmacol. 69, 230-237. Abstract: Skeletal muscle possesses inherent plasticity of gene expression. Low frequency pulse-train stimulation can remodel the biochemical machinery that confers physiological expression and fatigue resistance approaching that of the myocardium. This fatigue-resistant muscle can generate sufficient force to meet the power requirements for useful cardiac work. This ultimate goal is currently being pursued in models of cardiomyoplasty and muscle-powered cardiac assist devices. In this article, we review the three major subcellular systems subserving canine skeletal muscle transformation and compare them to those of cardiac muscle. The magnitude of the problem of clinical heart failure and the feasibility of fatigue-resistant skeletal muscle joining the therapeutic armamentarium are addressed. The adaptation and transformation of fast-twitch skeletal muscle in response to chronic electrical stimulation augers therapeutic potential as an endogenous, readily available power source for myocardial assistance. The basis mechanisms of skeletal
muscle fatigue require elucidation to gain a complete and thorough understanding of how to manipulate this property to provide continuous hemodynamic work.

Abstract: Dynamic cardiomyoplasty (DCM) involves the electrical stimulation of a pedicled latissimus dorsi muscle flap wrapped around the falling ventricle as a means of cardiac assist. To further elucidate a potential neurohumoral mechanism for improvement of cardiac output after myoplasty, we evaluated the hemodynamic effects of in situ stimulation of the latissimus dorsi muscle (in the absence of cardiomyoplasty). In seven mongrel dogs, a nerve cuff electrode (Medtronic 6901) was placed around the left thoracodorsal nerve (TDN). This was attached to a pulse generator (Medtronic, Itrel 7420), delivering a 4.0 volt, 0.19 second on, 0.81 second off, 33 Hz, 210 microsecond pulse width, cyclic bursts similar to that used in DCM. Stroke volume index (SVI) and other hemodynamic parameters as well as plasma norepinephrine (NE) levels were measured at five stages: baseline, stimulator on at 0, 2, and 5 minutes, and stimulator off at 30 minutes after. The animals were then subjected to 4 weeks of rapid pacing at 240 beats/min (Medtronic 8329) to induce heart failure, and as the rapid pacing was discontinued, measurements were repeated as above. After rapid pacing, cardiac function was significantly depressed, and NE was elevated (133 +/- 69 versus 500 +/- 353 pg/mL, p < 0.05). In the normal hearts, TDN stimulation increased SVI, heart rate, systemic pressure, and NE levels. In heart failure, however, no significant changes in cardiac function and NE levels were noted. In conclusion, our data indicate that in the normal hearts, afferent impulses from TDN stimulation alone may augment cardiac function by means of a neurohumoral effect that is not seen in severe heart failure. The implications of these findings in DCM are discussed.

Abstract: We have been studying feasible surgical alternatives for treating congestive heart failure, including the use of cardiomyoplasty. In this operation, skeletal muscles are conditioned, through electrical stimulation, to provide active tension on diseased myocardium, which improves left ventricular performance and ultimately increases cardiac output. We performed cardiomyoplasty in a 37-year-old man with severe ischemic cardiomyopathy. He was discharged from the hospital 2.5 months after the operation, and he did not require medical therapy. We believe this to be the 1st cardiomyoplasty performed in Ukraine.

Abstract: Patients with severe chronic heart failure (CHF) suffer from marked weakness of skeletal muscles. Neuromuscular electrical stimulation (NMES) proved to be an alternative to active strength training. The objective of this study was to test the feasibility and effectiveness of NMES in patients with chronic heart failure. Seven patients (56.0 +/- 5.0 years, CHF for 20 +/- 4 months, left ventricular ejection fraction 20.1 +/- 10.0%) finished an 8 week course of NMES of the knee extensor muscles. The stimulator delivered biphasic, symmetric, constant voltage impulses of 0.7 ms pulse width with a frequency of 50 Hz, 2 s on and 6 s off. No adverse effects.
occurred. After the stimulation period, the isokinetic peak torque of the knee extensor muscles increased by 13% from 101.0 +/- 8.7 Nm to 113.5 +/- 7.2 Nm (p = 0.004). The maximal isometric strength increased by 20% from 294.3 +/- 19.6 N to 354.14 +/- 15.7 N (p = 0.04). This increased muscle strength could be maintained in a 20 min fatigue test indicating decreased muscle fatigue. These results demonstrate that NMES of skeletal muscles in patients with severe chronic heart failure is a promising method for strength training in this group of patients.


Abstract: OBJECTIVE: To determine the impact of an 8-wk neuromuscular stimulation program of thigh muscles on strength and cross-sectional area in patients with refractory heart failure listed for transplantation. DESIGN: Forty-two patients with a stable disease course were assigned randomly to a stimulation group (SG) or a control group (CG). The stimulation protocol consisted of biphasic symmetric impulses with a frequency of 50 Hz and an on/off regime of 2/6 sec. RESULTS: Primary outcome measures were isometric and isokinetic thigh muscle strength and muscle cross-sectional area. Our results showed an increase of muscle strength by mean 22.7 for knee extensor and by 35.4 for knee flexor muscles. The CG remained unchanged or decreased by -8.4 in extensor strength. Cross-sectional area increased in the SG by 15.5 and in the CG by 1.7. CONCLUSIONS: Activities of daily living as well as quality of life increased in the SG but not in the CG. Subscales of the SF-36 increased significantly in the SG, especially concerning physical functioning by +7.5 (1.3-30.0), emotional role by +33.3 (0-66.6), and social functioning by +18.8 (0-46.9), all P < 0.05. Neither a change nor a decrease was observed in the CG.


Abstract: OBJECTIVE: Dynamic cardiomyoplasty, using a functional graft of the latissimus dorsi muscle, has shown promise as a treatment for selected patients with advanced heart failure. The success of this approach depends on maintaining the viability of the muscle, whose distal portion is susceptible to ischaemic damage. We investigated the effects of surgical mobilization on regional muscle blood flow and
the influence of electrical stimulation of the muscle. METHODS: Ten sheep were randomly assigned to two equal groups. In one group, the latissimus dorsi muscle was stimulated continuously in situ at 2 Hz for two weeks; in the other group, the muscle was not stimulated. Regional blood flows in the muscles were determined by a fluorescent microsphere technique. Serial measurements were made (a) under baseline conditions before intervention, (b) with the thoracodorsal artery occluded and (c) after interruption of the perforating collateral arteries. RESULTS: Surgical mobilization of the unstimulated latissimus dorsi muscles had little effect on blood flow in the proximal region, which remained at 93.1 +/- 16.9% of baseline (mean +/- SEM). The distal region was rendered significantly more ischaemic (55.8 +/- 13.5% of baseline, p < 0.002 compared to the proximal region). Electrical prestimulation abolished any significant proximodistal gradient in blood flow and improved distal muscle perfusion following mobilization (proximal vs. distal: 75.0 +/- 8.8 vs. 63.0 +/- 10.9%; p > 0.4). CONCLUSIONS: Distal muscle ischaemia occurred when the entire latissimus dorsi muscle was acutely elevated on the thoracodorsal pedicle alone. Electrical prestimulation of the muscle in situ improved the thoracodorsal perfusion of the distal muscle by abolishing the proximal-to-distal gradient in flow, with a substantial benefit to distal flow after mobilization. Although electrical stimulation is known to induce vascular proliferation, we argue that this effect of stimulation is brought about mainly by enhancement of the flow through anastomotic connections between proximal and distal arterial territories.


Thelin S., Vedung S., Nylund U., and Thorelius J. (1992) Experimental dynamic cardiomyoplasty in sheep. Scand. J. Thorac. Cardiovasc. Surg. 26, 1-7. Abstract: To evaluate electrically stimulated muscle grafts for augmenting ventricular function in cardiac insufficiency, dynamic cardiomyoplasty was performed in nine sheep, using latissimus dorsi (LD) muscle wrapped as a pedicle around the left ventricle. Beginning 2 weeks postoperatively, LD was stimulated synchronously with the heart. After 6 and 12 weeks of stimulation, hemodynamic evaluation was done and biopsies were taken for histochemical and biochemical analysis. With intact heart function, stimulation of the muscle was not hemodynamically beneficial. During induced heart failure, cardiomyoplasty increased cardiac output by 25% in two sheep. Eight LD muscles contracted vigorously in synchrony with the heart, one was fibrosed and all were fixed to the thoracotomy incision by scar tissue. ATPase stain showed gradual transformation of muscle fibers into fatigue-resistant Type I. At 12 weeks only Type I were seen. Quantitative enzymatic analyses revealed increase in oxidative and decrease in glycolytic enzymes. Chronic electrical stimulation is concluded to change the muscle characteristics towards those of mainly oxidative and fatigue-resistant muscle, thereby improving opportunities for assisting the depressed heart.


apex to aorta configuration: up to eight months in circulation. *J Thorac Cardiovasc Surg* 116, 1029-1042.


Abstract: BACKGROUND: The latissimus dorsi is usually left unstimulated for 2 weeks after cardiomyoplasty to allow the muscle to recover from the loss of the collateral circulation. To determine whether the 2-week delay may cause muscle atrophy, we randomized 15 mongrel dogs to a control group or a disuse atrophy group. METHODS: The collateral circulation to the latissimus dorsi was ligated in all animals before cardiomyoplasty to reduce the risk of ischemic injury to the muscle during mobilization. Two weeks after collateral ligation, the atrophy group had the tendinous attachment of the latissimus dorsi severed and then 2 weeks later underwent cardiomyoplasty. The control group had a 2-week delay after collateral ligation followed by cardiomyoplasty. Biopsies were performed before collateral ligation and before cardiomyoplasty. After heart failure was induced, hemodynamic function was assessed during synchronized contraction of the latissimus dorsi by measuring the maximum systolic elastance, stroke volume, preload recruitable stroke work index, and diastolic compliance. RESULTS: Comparison of muscle morphology between the two groups demonstrated the presence of muscle atrophy in those animals that had been randomized to the atrophy protocol. During synchronized contraction of the latissimus dorsi, there was no significant increase in maximum systolic elastance in either group. However, both stroke volume and pulmonary recruitable stroke work index were significantly higher in the control animals during assisted beats. The left ventricle was less compliant in the atrophy group, suggesting that muscle atrophy had adversely affected diastolic function. CONCLUSIONS: Delayed electrical stimulation of the latissimus dorsi may result in atrophy and loss of function.