Imaging of Skeletal Muscle Contraction after Cardiomyoplasty

Marieke Smink, Frederik H. van der Veen, Koen Reesink, Roberto Lorusso(1), Mario Barbiero(2),Mauritio Volterrani(3),Theo van der Nagel and Ugo Carraro(4)

Cardiovascular Research Institute Maastricht, The Netherlands, (1) Department of Cardiothoracic Surgery, Brescia, (2) Division of Cardiology, Legnago General Hospital, Legnago, Verona, (3) Department of Cardiology , Gussago, Brescia and (4) CNR Unit for Muscle Biology and Physiopathology, University of Padua, Italy

Abstract

The clinical interest in cardiac assist with a wrapped skeletal muscle has reduced in recent years, due to disappointing clinical results. Two causes might be responsible for these results. Firstly, gradual degeneration of the muscle, and secondly, transformation of the muscle into a slow and less powerful muscle. The Demand dynamic cardiomyoplasty was developed to reduce the muscle workload and so to improve muscle condition.

Two methods were developed earlier to study skeletal muscle characteristics after cardiomyoplasty. Firstly, fluoroscopic evaluation of LD muscle contraction by X-ray imaging of the stimulation electrodes within the muscle. Secondly, the mechanogram method was used which records extra-thoracic LD muscle movement. In the present study 5 patients were included, of which two patients had been stimulated according to the demand protocol, and three patients according to the daily protocol.

The mechanogram and the X-ray methods are both suitable to generate graphs which show individual contraction cycles, and can be used for further analysis. The results of these analysis showed that the two methods were comparable. The stimulator delay could be calculated (70-73 msec), and a physiological delay between the electrical pulse and muscle contraction appeared to last 31-34 msec. Also, the total contraction time was comparable as measured with both methods, respectively 381 and 386 msec.

Differences between the demand and the daily stimulated patients were not present at the clinical stimulator settings. However, at increased amplitudes the cycle length's appeared to be shorter in the demand group, in particular when bursts of 6 pulses were applied.

In conclusion, the mechanogram offers a reliable, fast, cheap and non-invasive method to study the LD muscle in patients after cardiomyoplasty. The demand dynamic cardiomyoplasty stimulation protocol tends to keep the LD muscle as a relatively fast muscle, which might be advantageous in these patients.

Key words: cardiac assist, Latissimus dorsi, patients, X-ray imaging.

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Cardiac assist with harvested skeletal Latissimus dorsi (LD) muscle, well known as cardiomyoplasty, has been matter of several research programs in recent years, but is at present nearly an abandoned area of investigation. Initially, controversial results of both preclinical as well as clinical studies were the cause of a tempered enthusiasm for treating class III patients. Subsequently, disappointing outcome of clinical trials urged most clinicians, researchers, and industrial supporters to reduce their investments in this field.

At present, two causes are held responsible for the disappointing results of patient studies. Firstly, gradual degeneration of the harvested LD muscle due to the high work load and the surgical disconnection of collateral blood circulation to the distal part of the LD muscle [7]. Secondly, gradual transformation of the electrically stimulated muscle appeared to generate a fatigue resistant predominantly fiber type I muscle, however, with reduced muscle power output and contractile speed [5].

One approach to deal with the two above mentioned causes would be to reduce the workload to the muscle, and so to prevent reduction in power output. This approach was presented as the "Demand Dynamic Cardiomyoplasty" [1]. Clinical application of this method showed that the tetanic fusion frequency occurred at a much higher frequency [3]. However, proper evaluation of LD muscle properties was not possible in patients in the past. Therefore, two non-invasive methods were developed to monitor LD muscle activity and properties within the thorax. One method uses X-ray images of the stimulation electrodes within the LD muscle. The changing distance between these electrodes is calculated and from these data contraction cycles are generated [Lucas]. The second method is also called the mechanogram and records the pressure at the place of LD muscle insertion into the thorax [3]. In the present study these two methods were compared in five cardiomyoplasty patients. Three patients had been on the routine stimulation protocol, while two patients had been stimulated according to the demand dynamic stimulation protocol.

Material and Methods

The study was performed at the local hospital in Gussago, Italy. Five patients were measured (1 female, 4 males) in the age between 48 and 66. The patients who were selected had a CMP operation at least two years before and subsequently a uniform LD muscle stimulation protocol. Patients 1 and 2 were stimulated on demand whereby the stimulator was only activated during daily activities and switched off during bed rest [3]. Patients 3, 4 and 5 were continuously stimulated according to the routine clinical protocol, however the heart: LD muscle ratio was reduced to 1:3 or 1:4 (Table 1). The first two patients had been operated in Padova and the other three in Brescia.

CMP was performed as described by Chachques and Carpentier [2] using the Medtronic stimulator and stimulation electrodes.

The voltage amplitude selected in these patients ranged from 2.8-7.4 V (Table 1). During the first measurement the clinical setting was studied. Thereafter, the voltage amplitude and the number of pulses were adjusted (Table 2). The voltage was increased (in 4 patients) to have a temporary maximum shortening, also referred to as the best setting. The number of pulses was increased stepwise from 1 to 6. The stimulator delay (55-86 ms), the ratio (1:3/1:4) and the time between the pulses were not changed.

During each setting at least 3 cardiac cycles were recorded on video (x-ray, mechanogram and ECG), on the hard disk of the PC (mechanogram and ECG) and on a paper recorder (polygraph). The mechanographic evaluation of LD contraction was performed by extrathoracic recording of the LD movement at the place of insertion with an external membrane pressure transducer on the skin [3]. Data processing was performed with the FILEVIEW software package.

The X-ray equipment used was a SM9 (SIAS). The images of the X-ray were directly recorded on video. Data processing of the X-ray was performed with XIMAC (X-ray Images Measurements for Analyzing Contractions), developed by the General Instrumental Service and the department of Cardiology at the University of Maastricht. Average values were calculated from at least two LD muscle contractions in every setting. The software package EXCEL was used to generate muscle contraction cycles.

Several time episodes were obtained from these contraction cycles (see Tables 4 and 5):
Delay 1 = the time interval between the beginning of the QRS-complex and the beginning of the burst.
Delay 2 = the time interval between the beginning of the burst and the beginning of the contraction cycle. These values could be measured because ECG, X-ray images, and the mechanogram were recorded simultaneously.

Results

Five patients were admitted to compare the X-ray method with the mechanogram method at different stimulator settings (Table 1). Two patients were on the demand stimulation protocol and the other three patients were on the daily stimulation protocol. At the clinical stimulation setting rather short bursts of 4-5 pulses, and a low ratio of skeletal muscle stimulation to heart contraction, had been installed routinely.

Registration of the mechanogram revealed distinctive graphs, which could be analyzed directly, because the ECG and the stimulator burst were recorded on line with the relative pressure signal (Figure 1). In this way the X-ray method differs from the mechanogram method, because each graph has to be drawn from the measured values obtained on the video screen. Figure 2 presents graphs obtained with both methods in one pa-

Table 1. Patient information and clinical stimulator settings (number of pulses, voltage, LD muscle: heart ratio).

Patient nr.	gender	age	Years after CMP	stimulation protocol	delay (ms)	clinical setting	time between pulses (ms
1.	m	48	2	Demand	55	4p;3.4v; 1:3	23
2.	f	51	2	Demand	86	4p;2.8v; 1:3	23
3.	m	66	4	Constant	55	5p;4.0v; 1:4	31
4.	m	57	4	Constant	70	4p;7.4v; 1:3	23
5.	m	64	5	Constant	55	4p;3.0v; 1:4	23

Table 2. Time frames of different parts of one LD muscle cycle at three different settings with the mechanogram method (ms).

	D1	D2	contraction time	tetanic phase	relaxation time	cycle length
Clinical setting						
Mean	70	31	103	103	175	381
SD	19	19	31	27	35	29
1 pulse						
Mean	82	14	65	58	144	267
SD	23	1	26	31	14	49
6 pulses						
Mean	79	19	93	99	188	381
SD	13	6	46	52	59	86

tient using a 6 pulse burst.

These graphs were used to analyze the LD muscle contraction cycle at all test settings. Tables 2 and 3 present the time frames which were distinguished from each cycle, as is explained in the method section.

At all test settings the duration of D1 and D2 was comparable between the two methods. The first delay (D1) ranged from a mean value of 57 to 82 msec, while the second delay (D2) was in the range of 14-34 msec.

The three phases of the contraction cycle could be distinguished with both methods. The contraction phase was not different between the two methods, whereas the tetanic phase and the relaxation phase appeared to show differences. The tetanic phase was longer with the mechanogram at the clinical setting, but shorter at 6 pulses measured with the mechanogram. The relaxation phase was only longer at single pulse stimulation with the mechanogram if compared to the X-ray.

Analyses of the contraction cycle revealed some differences between the patients who had been stimulated daily, and the patients who had been stimulated on demand (Tables 4 and 5). Although only five patients were studied, the cycle lengths were shorter at all best settings in the demand group. Only at the clinical setting the cycle lengths were longer in the demand group as measured with the mechanogram method.

The sensitivity of the mechanogram method was further analyzed by comparing contraction cycles when bursts were programmed with 1, 2, 3, and 6 pulses (Figure 3). Both gradual increases in cycle length's and in amplitude were observed.

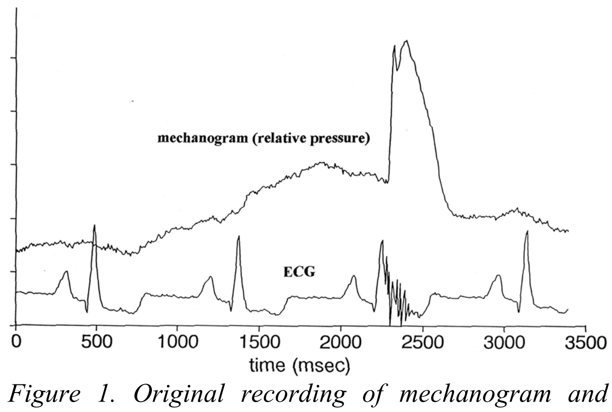

Figure 1. Original recording of mechanogram and ECG of one contraction cycle. Note the relative value of the pressure measurement, and the ECG spikes caused by the skeletal muscle stimulator.

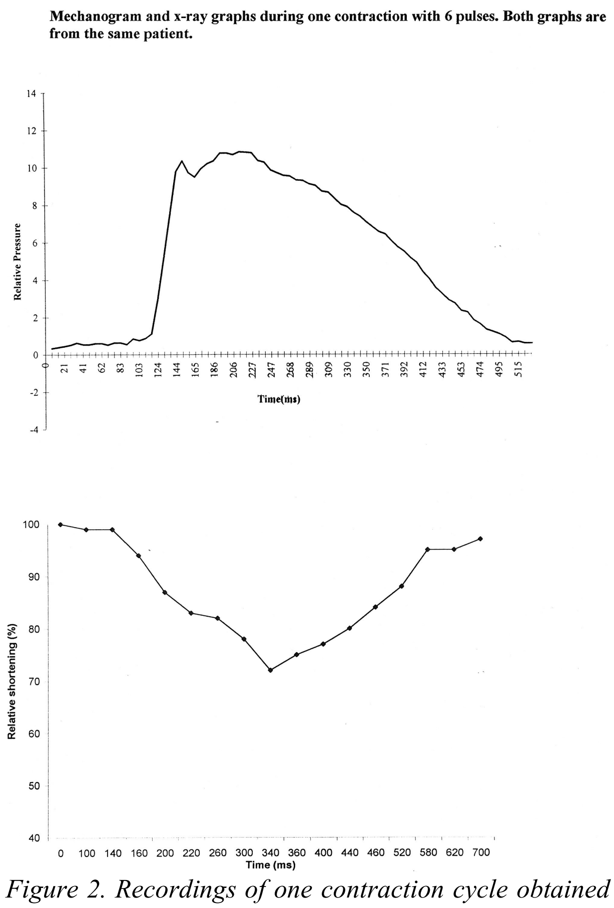

Figure 2. Recordings of one contraction cycle obtained with the mechanogram (upper part) and with the X-ray method, as used for further analysis. The muscle was stimulated at 6 pulses.

Table 3. Time frames of different parts of one LD muscle cycle at three different settings with the X-ray method (ms).

	D1	D2	contraction time	tetanic phase	relaxation time	cycle length
Clinical setting						
Mean	73	34	130	60	196	386
SD	19	19	45	25	85	120
1 pulse						
Mean	60	33	60	72	88	192
SD	28	12	47	63	39	41
6 pulses						
Mean	57	23	85	195	175	455
SD	6	15	19	66	85	129

Table 4. The cycle length (ms) of the two groups measured with the X-ray method are presented at three different settings (mean values).

	1 pulse	4 –5 pulses (clinical setting)	6 pulses
Demand	150	355	340
Daily	220	406	493

Table 5. The cycle length (ms) of the two groups measured with the mechanogram method are presented at three different settings (mean values).

	1 pulse	4-5 pulses (clinical setting)	6 pulses
Demand	261	390	305
Daily	272	375	403

Discussion

The aim of this study was to compare the mechanogram method with the X-ray method, both developed to assess the LD muscle contraction in cardiomyoplasty (CMP) patients.

Although the study group involved only 5 patients, a second objective was to determine whether a difference in muscle properties could be detected between patients who had been stimulated daily or on demand. This is an important issue in CMP, because fast and powerful muscles are requested in CMP, while constant electrical stimulation has shown to transform the skeletal muscle in a slow and less-powerful muscle [5, 6].

In the present study the X-ray method appeared very sensitive to analyze the LD muscle contraction cycle. However, this method performs analysis off-line and the analysis is time consuming. In contrast, the mechanogram method is on-line and analysis can be performed instantaneous. An additional disadvantage is that the X-ray method delivers radiation to other tissues as well.

Comparison of the two methods to analyze muscle contraction showed that both methods are sensitive

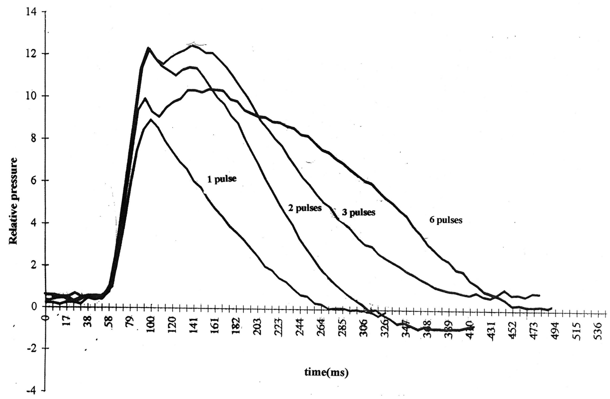

Figure 3. Contraction cycles obtained with the mechanogram at 1, 2, 3, and 6 pulses in one patient.

enough for the intended purpose. The delay (D1) between the QRS complex and the start of the stimulator burst was programmed at 55 to 86 msec in the five patients, and a mean delay of 70 to 73 msec was measured. The delay (D2) between the start of the burst and the beginning of contraction lasted 31 to 34 msec. This delay should be included in further functional studies for proper stimulator setting [4, 8].

Unfortunately, in earlier studies the mechanogram method was used to determine the Tetanic Fusion Frequency [3], without calculation of the cycle lengths. However, the conclusion that demand stimulation resulted in faster contracting muscles was confirmed in the present study. A reduction of at least 100 msec for the contraction cycle may indicate that the muscle has not been transformed entirely into a slow type I fibre muscle. This assumption of course has to be confirmed from muscle biopsies.

Whereas the cycle length appears to be shorter after demand stimulation than after daily stimulation, the cycle length as such is much shorter than observed in cardiomyoplasty patients with a 1:2 heart LD muscle ratio. In these patients a cycle length of 660 msec was reported after chronic electrical stimulation [9].

Address for correspondence:

Dr Ir FH van der Veen, Cardiothoracic Surgery, PO Box 5800, 6202 AZ, Academic Hospital, Maastricht, Netherlands, Email FVV@SCPC.AZM.NL.

References

[1] Arpesella G, Mikus P, Giancola R, Pierangeli A, Giannoni A, Miracoli L, Rizzi C, Rossini K, Bruson A, Catani C, Carraro U: Functional and structural characteristics of Sheep LD conditioned to fatigue resistance by a half-day cardiac-like electrostimulation protocol: Implications for dynamic cardiomyoplasty. *BAM* 1995; 5: 103-107.

[2] Carpentier A, Chachques JC: Latissimus dorsi cardiomyoplasty to increase cardiac output. Mt. Kisco, N.Y., Futura Publishing Co., 1987, 473-486.

[3] Carraro U, Docali G, Barbiero M, Brunazzi C, Gealow K, Casarotto D, Muneretto C: Demand dynamic Cardiomyoplasty: Improved clinical benefits by non-invasive monitoring of LD flap and long-term tuning of its dynamic contractile characteristics by activity-rest regime. *Basic Appl Myol* 1998; 8: 11-15.

[4] Grandjean P: Dynamic myoplasty: surgical transfer and stimulation of skeletal muscle for functional substitution or enhancement. *J-Rehabil-Res-Dev* 1996; 33: 133-144.

[5] Jarvis JC, Kwende MMN, Shortland A, Eloakley RM, Gilroy SJ, Black RA, Salmons S: Relation between muscle contraction speed and hydraulic performance in skeletal muscle ventricles. *Circulation* 1997; 96: 2368-2375.

[6] Lucas CM, van der Veen FH, Cheriex EC, van Ommen V, Penn OC, Wellens HJ: The importance of muscle relaxation in dynamic cardiomyoplasty. *PACE* 1992; 15: 1430-1436.

[7] Lucas CMHB, van der Veen FH, Cheriex EC, Lorusso R, Havenith M, Penn OCKM, Wellens HJJ: Long-term follow-up after dynamic cardiomyoplasty in goats. *JACC* 1993; 22: 3, 758-767.

[8] Schreuder JJ, van der Veen FH, van der Velde ET, Delahaye F, Alfieri O, Jegaden O, Lorusso R, Jansen JRC, Finet G, Kaulbach H, Wellens HJJ: Left ventricular pressure-volume relationships pre- and post cardiomyoplasty in heart failure patients. *Circulation* 1997; 96: 2978-2986.

[9] van der Veen FH, Lucas CMHB, Lorusso R, van der Nagel T, Penn OCKM, Wellens HJJ: A new method to select stimulus strength after cardiomyoplasty. *J Cardiac Surg* 1991; Vol 6, No 1, Suppl 259-264.