

Anthropometric Study of the Pectoralis Minor Muscle as a Power Source to a Bio-pump in Terminal Insufficiency of the Heart Muscle

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Abstract

The study concerned the possibility of using superficial skeletal muscles of the thorax as a power source to a bio-pump used for supporting the hemodynamically insufficient heart muscle. Having thoroughly analyzed the topography, ways and sources of blood supply to the muscles, the pectoralis minor muscle was selected as the most suitable one for this purpose.

Keywords: Muscular flaps; Pectoral muscles; Biopowering; Cardiac assistance; Assist device (bio-pump)

Introduction

The first ideas concerning a possibility of artificial support of the cardiovascular system appeared as early as 200 years ago. In 1812 Le Gallois pointed to possibilities of temporary or permanent support of the failing heart [1]. However, many years had passed before the joined engineering and medical effort resulted in the first clinical use of mechanical support of circulation. The first reports of studies on the artificial heart (AH) were published in 1958 by Akutsu and Kolff [2]. In 1961 Dennis was the first to use a roller pump to support the left ventricle (LVAD) [3]. In 1962 Moulopoulos, Topaz and Kolff pioneered in using the intra-aortic balloon pump (IABP) [4]. In 1963 De Bakey and Liotta used successfully the pulsating ventricular assist device in patients in cardiogenic shock postcardiotomy [5]. In 1969, Cooley and Liotta reported the first clinical case of implantation of the artificial heart [6]. Since then many institutions worldwide had carried out intensive research, which led to the development of many devices used in clinical practice to support the insufficient circulatory system.

Currently, a terminally failing heart can be supported by the following methods:

- Biological: heart transplantation or reconstructive surgery [7-12].
- Mechanical: various systems of ventricular support and total heart prostheses [2-6,13-16],
- Biomechanical: dynamic cardiomyoplasty (DC) and assist devices [17-28].

Dynamic cardiomyoplasty

Dynamic cardiomyoplasty involves using the force of contraction of a skeletal muscle to support the work of the failing heart [17]. The heart is wrapped with a pedicled muscular flap (with a preserved bundle of vessels and nerves supplying the skeletal muscle) and trained with the use of electrical stimulation. A suitable pacemaker coordinates the work of the skeletal muscle and the heart (Figure 1) [17,29,30].

Studies revealing great plasticity of biochemical and histological changes of electrically stimulated skeletal muscles were of essential importance for this form of treatment. Training a skeletal muscle according to a suitable protocol of electrical stimulation leads to a number of changes in the structure and cytoarchitecture of the fibers of skeletal muscle as well as its enzymatic activity and metabolism [30-33].

The above-mentioned changes lead to transformation of muscle fibers Type II (fatiguable fast-twitch muscle fibers with prevalence of glycolytic metabolic processes) into muscle fibers Type I (fatigue-resistant slow-twitch muscle fibers with prevalence of oxidative metabolic processes). Thanks to this, the skeletal muscle after the process of training with electrical stimulation is able to contract in accordance with the heart rate without fatigue for many years.

In some cases dynamic cardiomyoplasty may be an alternative to heart transplantation. The first successful operations of this type in Poland were carried out in Krakow in 1996 [23,24].

As the hemodynamic research and clinical experience carried out so far have shown, dynamic cardiomyoplasty is rather a passive support of the heart. Its main mechanism of action is to:

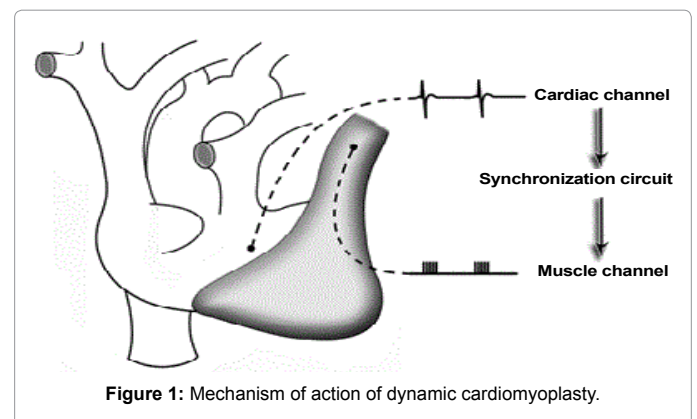


Figure 1: Mechanism of action of dynamic cardiomyoplasty.

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- Stop the dilation of the heart chambers (kind of external support),
- Reduce the tension of the heart walls thus resulting in a decreased use of oxygen by the heart muscle, which is particularly important in case of ischemic cardiomyopathy – a common cause of heart failure,
- Improve the contractility of the heart muscle increasing the so-called ejection fraction (EF) [15,17,19-21,25].

However, the last of the above-mentioned effects of dynamic cardiomyoplasty is relatively insignificant. That is why in most cases a quick improvement within the hemodynamic parameters and clinical viability of the patient is impossible, which in turn considerably limits the possibility of using this method.

Bio-pumps

The assist devices designed so far have been based on wrapping the blood-filled pouch with a skeletal muscle. However, such structures cannot be used for long-term assist for several fundamental reasons, which have disqualified its widespread clinical use in humans. The most significant drawbacks include:

- Thromboembolic complications: the muscle wrapped around the ventricle does not exert pressure evenly on the blood-filled pouch, which results from a different thickness of the muscle and different directions of contractions of muscle fibers in its particular areas (Figure 2) [24]. Due to this the so-called dead zones appear in the ventricle as well as blood turbulence considerably disturbing its laminar flow,
- Poor diastolic susceptibility of the ventricle: the wrapping muscle mass, even in diastole, is hardly elastic, which results in a decreased blood supply and, according to Laplace's law, reduces the initial ventricular wall tension thus decreasing the efficiency of muscle contraction,
- Rupture of the muscular ventricle,
- Complicated surgical procedure.

In order to avoid the above-mentioned drawbacks, a new prototype of a bio-pump was developed. A fundamental assumption was a change in the way of powering the ventricle by a skeletal muscle. The force of shortening of the muscle was supposed to be used, thus abandoning the idea of exerting pressure on the ventricle by muscle mass. In the prototype discussed an intermediary medium (liquid) around the blood-filled pouch was supposed to be present. Through the indirect mechanism the force of the contraction of the muscle causes an increase in the pressure of the intermediary medium, which in turn increases the pressure in the blood-filled pouch and ejection fraction (Figure 3).

A substantial problem remains the type of muscle, which due to its anatomical position and its dimensions could be the power source to the new prototype of a bio-pump. The below study is an attempt to address this issue.

Materials and Methods

An anthropometric study was carried out at the Department of Anatomy of the Jagiellonian University Medical College in Krakow on 6 male and 4 female dead bodies aged 52-68. The study focused on the topographic conditions of the superficial skeletal muscles of the thorax as a potential power source to an assist device as well as on the origin and distribution of arteries supplying these muscles. Considering their anatomical conditions two muscles have been selected from among the superficial muscles of the thorax to serve as a power source to a bio-pump: the pectoralis major and the pectoralis minor. Their topographic

position, location of the initial and terminal attachment(s) on the lateral and anterior medial side of the thorax as well as the proximity of the potential opening where there is a technical possibility of relocating the muscles into the thorax, and at the same time a relatively great mobility of the vascular pedicle make these muscles an optimum choice for this purpose. Besides, the connective tissue termination of both attachments of the muscles facilitates fixing them to the arm powering the bio-pump. In order to identify the vessels more easily, their lumen was filled with a solution of gelatin dyed red with ink, injecting the vessels from the side of the clavicular and cervical common arteries, and the ascending aorta. The distribution of the vessels was subject to macroscopic assessment. Having established the power source in the form of the pectoralis minor muscle, the shape and dimensions of the assist device were optimized by adjusting it to the conditions within the mediastinum. The curvatures and dimensions were modified in view of the parameters of the human constitution, topography of the heart, lungs, and the location of the pacemaker (Table 1) contains general data on the number of corpses, their gender, weight, and measurement data concerning the pectoralis minor muscles. (Table 1 and Figure 4).

Pectoralis major muscle – commences with three attachments. The top portion (clavicular) arises from the medial half of the clavicle; the middle portion (sternocostal) – on the anterior surface of the sternum and cartilages of true ribs; the lower part (abdominal), sometimes absent, is attached to the lamina of the anterior sheath of the rectus

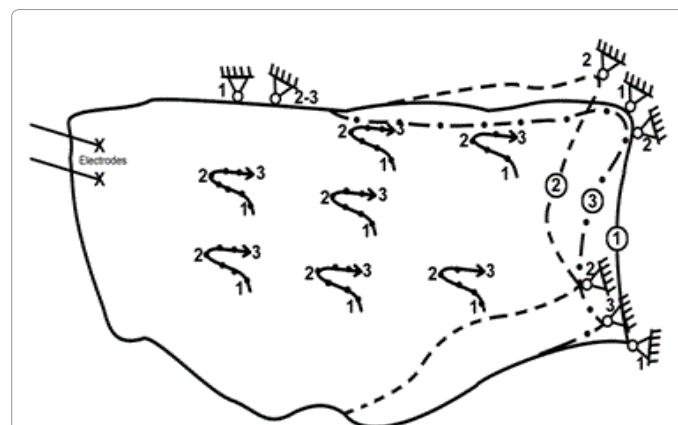


Figure 2: Below trajectories of the contraction of the tense latissimus dorsi muscle in a dog marked with luminophores. Changes of position of the muscle (1, 2, 3) during contraction.

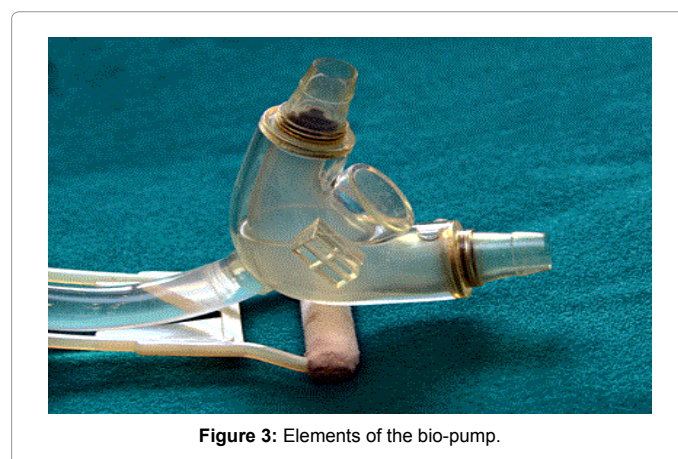


Figure 3: Elements of the bio-pump.

Number and gender of corpse	Weight [kg]	Height [cm]	Length of the hockey-stick incision [cm]	Length of the pectoralis minor muscle [cm]	Width of the pectoralis minor muscle, proximal portion, middle portion, distal portion / Area of triangle [cm/cm ²]	Thickness of the pectoralis minor muscle, proximal portion, middle portion, distal portion thickness / Volume by summation [cm/cm ³]	Weight of muscle [g]	% of patient's weight
1M	65	176	21	13	2/4/8/36	1·0/36	32·4	0·0498
2F	58	165	20	15	1·5/4·5/6/45	1·0/45	28·5	0·0491
3M	76	179	24	15	2/7·5/11/82·46	1·5/123·7	38	0·05
4F	52	168	20	12	1·7/3·5/8/48	0·8/38·4	25·4	0·0488
5M	85	170	22	14·5	2/5/9/62·25	1·2/78·3	40	0·047
6M	94	172	25	14	2/6/10/70	1·0/70	42·3	0·045
7F	60	168	21	15	1·3/4/8/60	0·8/48	30	0·05
8M	105	172	24	16	2·3/5·5/12/96	1·5/144	43·5	0·041
9M	86	169	22	13	1·5/7·5/9/58·5	1·0/58·5	37·5	0·043
10F	58	162	20	12	0·7/4·5/8/48	0·7/33·6	27	0·046

Table 1: Table containing basic data of patients and measurement of the pectoral minor muscles.

abdominis muscle. The muscle ends in a tendon of 5-7 cm in breadth which is inserted into the ridge of the greater tubercle of the humerus (Figure 5).

Pectoralis minor muscle – attachments: it commences with three or four fascicles on the outer surface of anterior ends of the second, third, fourth and fifth rib. Passing upwards and outwards, it ends in a short, strong tendon on the coracoid process of the scapula.

The source of blood supply to both muscles is the thoracoacromial artery, which is a branch of the first segment of the axillary artery, the lateral thoracic artery and, frequently, perforating branches of the intercostal vessels.

Results

The aim of the study was to select the most suitable muscle, to assess its vascular distribution and to determine the range of mobilization of the muscle dependent on the location and the length of the vascular pedicle. The following muscles were distinguished:

- of one vascular pedicle
- of two vascular pedicles with one of them being dominant
- of two vascular pedicles with both of equal dominance
- of pedicles dominant in the segmental blood supply [34].

Taking into consideration the position of the muscle, orientation of its fibers and the sources of the vascular distribution (having a direct influence on the possibility of mobilizing the muscle), it has been concluded that the pectoralis minor muscle is the more suitable with most of the desired features than pectoralis major muscle.

The muscle is supplied with the pectoral branch of the thoracoacromial artery, the lateral thoracic artery and perforating branches. Apart from the perforating branches, the blood supply to the pectoralis minor muscle is either dominated by a single pedicle of the thoracoacromial artery or bipediced blood supply of the lateral thoracic artery with the dominance of the pectoral branch of the thoracoacromial artery. The distribution of the thoracoacromial artery usually had a common segment of about 1 cm in length situated above the edge of the pectoralis minor muscle nearby the coracoid attachment. In 50% of cases this artery was divided into 4 independent

branches: pectoral, clavicular, acromial, and deltoid. In 20% of cases the division involved the branches: clavicular, pectoral, and a common trunk giving off the deltoid and acromial branches. In further 20% of cases the presence of the following branches was observed: deltoid, clavicular, and pectoral, where the acromial one branched off. In 10% of cases the thoracoacromial artery divided into 2 trunks, giving off in one case the deltoid and acromial branches, and in the other the pectoral and clavicular ones [34]. The variability in the mode of division of the thoracoacromial artery has no influence on the value of the pectoralis minor muscle as a pediced muscle powering a bio-pump (Figure 6).

The pectoral branches, which branch off as a common single trunk located always in the half length of the clavicle just above the top edge of both pectoralis muscles, are two branches: one reaches directly the pectoralis minor muscle, and the other supplies the pectoralis major muscle, situated about 1 cm below the acromioclavicular line.

The latter is of a permanent distribution [34]. The most common site of division is the top edge of the pectoralis minor muscle in the 1/3 nearer the coracoid attachment. If the division took place below the posterior surface of the pectoralis minor muscle, the branch supplying the pectoralis major muscle pierced the muscle located more deeply and reached the pectoralis major muscle together with the anterior thoracic nerves of the sub-clavian portion of the brachial plexus (Figure 7).

An additional source of blood supply is in half of the cases the lateral thoracic artery and in case of this muscle tiny branches of anterior intercostal arteries as perforating branches. As a source of blood supply, the latter are of no importance as they will have to be ligated during relocation of the muscles. The dominant pedicle in case of the 'bipediced' muscles (i.e. those with a double source of blood supply) was the pectoral branch of the thoracoacromial artery (Figure 8).

Moreover, it has been observed that in the material examined in more than 30% cases left- and right-side asymmetry occurred as far as the mode of division of pectoral branches is concerned. On the right side branches branching off as a common single trunk to the pectoralis muscles were found on the posterior surface of the pectoralis minor muscle, and then one of them (most frequently the top one) pierced the pectoralis minor and reached the pectoralis major muscle.

On the left side most frequently both branches to the pectoralis muscles branched independently off the site of division situated above

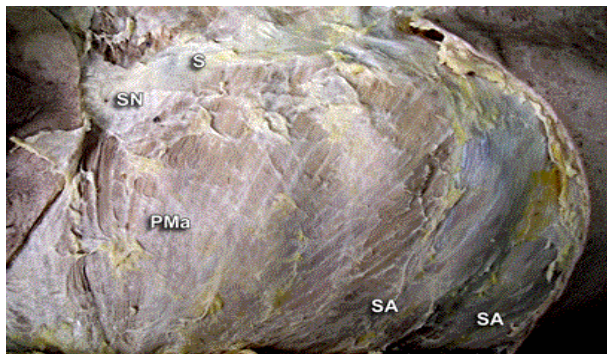


Figure 4: Superficial muscles of the thorax PMA – pectoralis major muscle, SA – serratus anterior muscle, S – sternum, SN – suprasternal notch.

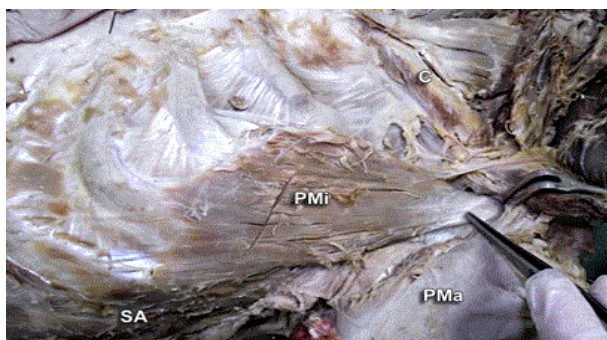


Figure 5: Pectoralis minor muscle PMA – pectoralis major muscle, PMi – pectoralis minor muscle, SA – serratus anterior muscle, C – clavicle.

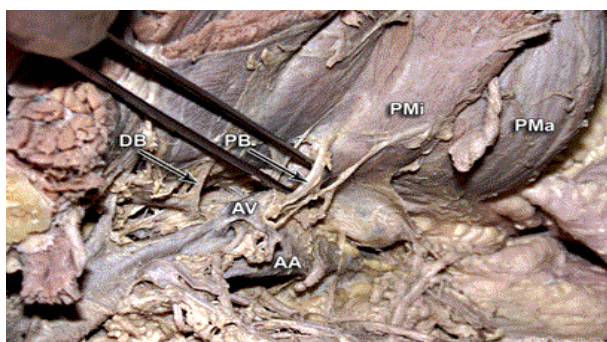


Figure 6: Thoracoacromial artery. DB – deltoid branch, AV – axillary vein, AA – axillary artery, PB – pectoral branch, PMA – pectoralis major muscle, PMi – pectoralis minor muscle.

the edge of the pectoralis minor muscle and reached each muscle as independent trunks. For this reason the vascular pedicle of the pectoralis minor muscle on the left gives the possibility of mobilizing it within a greater range than on the right side. Following the measurements in the autopsy material, the mobilization of the left pectoralis minor muscle seems to be possible within the range from 3 to 5 cm. On the right, however, mobilization is possible to the distance of about 3 cm due to the more frequent occurrence of the perforating branches (Figure 9).

In case of the pectoralis major muscle as a power source to a bio-pump, its partial mobilization is possible. However, it is technically limited due to extension of the initial attachments and the conflict

involving the transverse orientation of the vascular pedicle in relation to the direction of the fibers of the muscle fascia. The extended initial attachment is the cause of a fan-like arrangement of the fibers of the muscle fascia, so mainly the middle (or sternal) part of the muscle can be mobilized (Figure 10).

Methodology of obtaining the muscle flap from the left pectoral minor muscle (Figures 11-21).

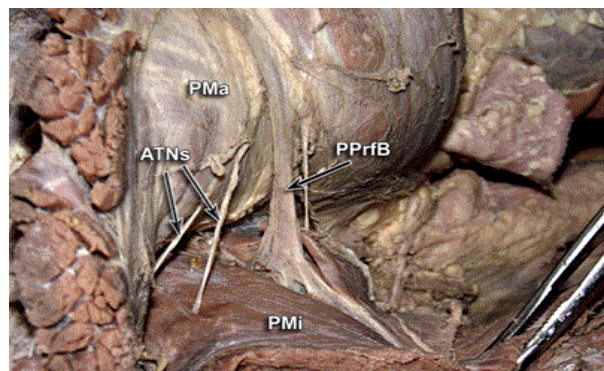


Figure 7: Pectoral branches and anterior thoracic nerves. PMA – pectoralis major muscle, PMi – pectoralis minor muscle, ATNs – anterior thoracic nerves, PPrFB – pectoral perforating branch.

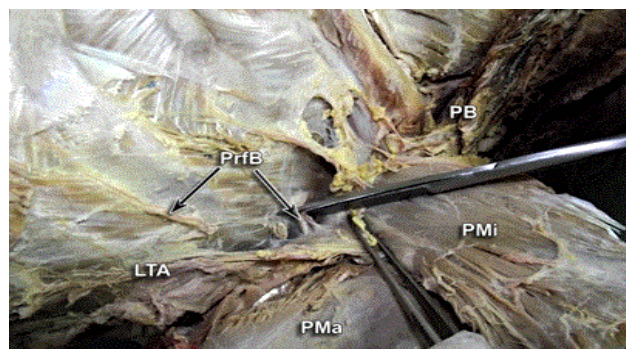


Figure 8: Arterial supply of the pectoralis minor muscle. PMA – pectoralis major muscle, PMi – pectoralis minor muscle, PB – pectoral branches, LTA – lateral thoracic artery, PrFB – perforating branches.

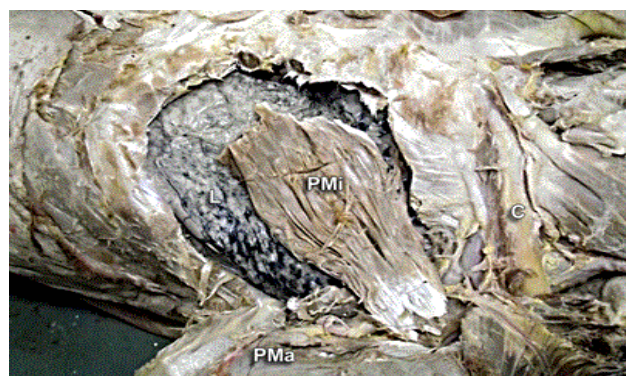


Figure 9: Mobilization of the left pectoralis minor muscle. PMA – pectoralis major muscle, PMi – pectoralis minor muscle, C – clavicle, L – lung.

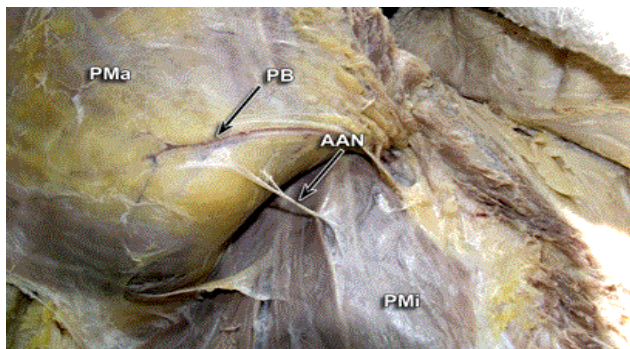


Figure 10: Pectoralis major muscle and its vessels. PB – pectoral branch, AAN – anterior axillary nerve, PMa – pectoralis major muscle, PMi – pectoralis minor muscle.

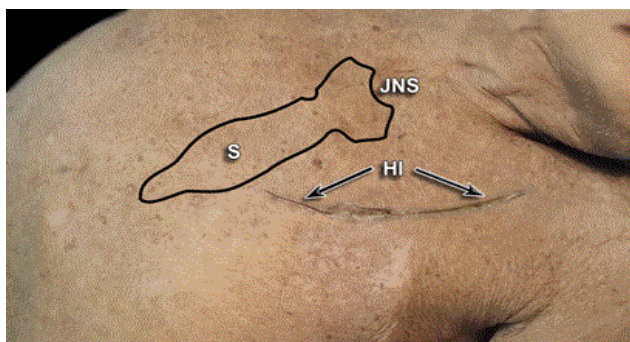


Figure 11: S – sternum, JNS – jugular notch of sternum, HI – "hockey" incision.

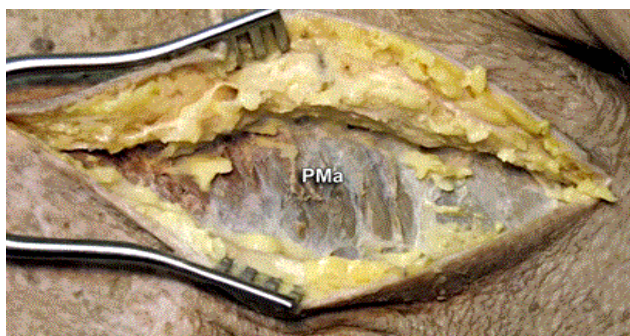


Figure 12: PMa – pectoralis major muscle.

Discussion

The musculo-cutaneous flap was first described by Ariyan in 1978 and has been used in reconstructive operations of the head and neck since then [35-39]. Muscular flaps used for functional cardiomyoplasty involving the pectoralis major, latissimus dorsi and serratus anterior muscles have been frequently described. Due to the permanent distribution of the pectoral branch in relation to the clavicle (in 1/2 of its length) and the distribution from 1/2 to 1 cm below the acromioclavicular line, the percutaneous location of this branch is easy [40]. Saraceno confirmed this in an angiographic study. Difficulty arises while determining the site of division of the same pectoral branch, which takes place in 1/3 'coracoid' length of the muscle and presence in nearly 50%

cases the other vascular pedicle of the lateral thoracic vessels. Because of the thoracoacromial pedicle being dominant, the other source is of no importance as far as mobilization of the muscle is concerned, and in experimental research it did not restrict the range of its mobilization. The differences in the mobilization distances between the left and right side do not matter in the methodology (except sinus inversus) because in most cases the left pectoralis minor muscle will be used [41].

From the statistical analysis the following conclusions may be drawn (Tables 2 and 3).

It has been observed that for such variables as:

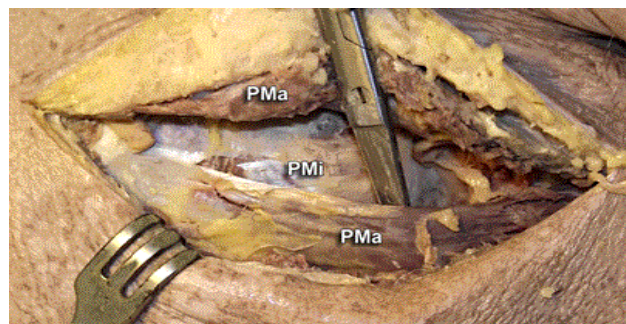


Figure 13: PMa – pectoralis major muscle, PMi – pectoralis minor muscle.

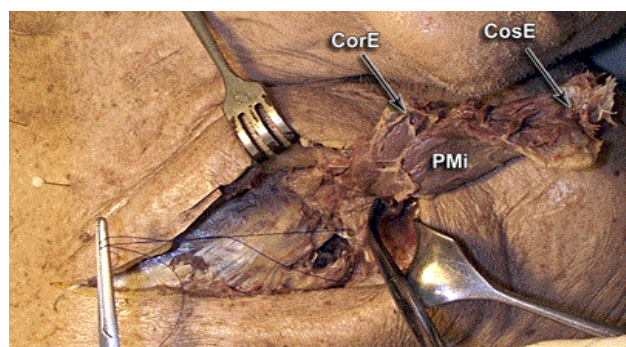


Figure 14: PMi – pectoralis minor muscle, CorE – coracoid end, CosE – costal end.

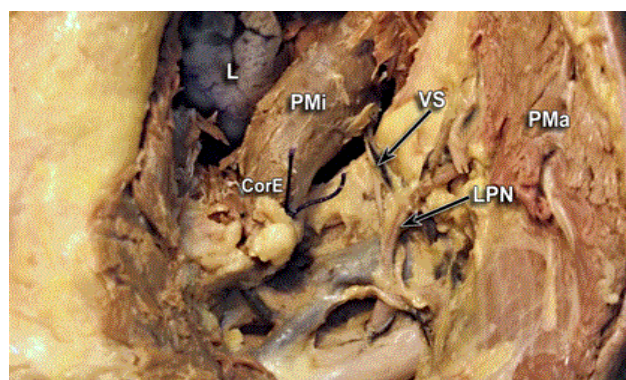


Figure 15: PMa – pectoralis major muscle, PMi – pectoralis minor muscle, CorE – coracoid end, L – lung, VS – vessel stalk, LPN – lateral pectoral nerve.

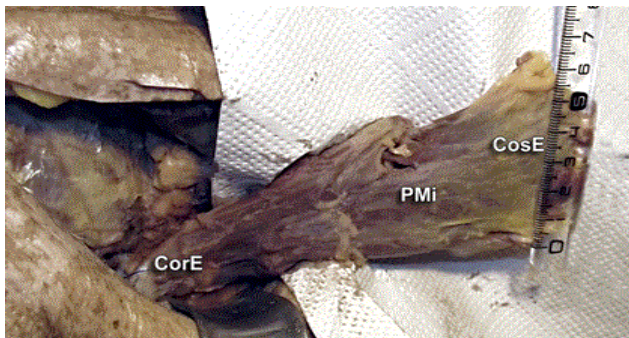


Figure 16: PMi – pectoralis minor muscle, CorE – coracoid end, CosE – costal end.

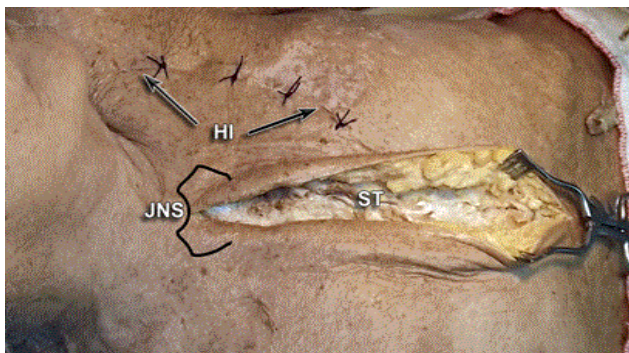


Figure 17: ST – sternotomy, JNS – jugular notch of sternum, HI – “hockeyincision”.

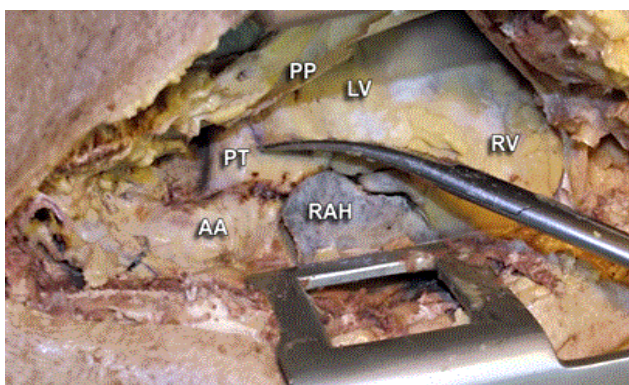


Figure 18: LV – left ventricle, RV – right ventricle, PP – parietal pleura, PT – pulmonary trunk, RAH – right article of heart.

- The length of the hockey-stick incision
- Width of the proximal portion
- Width of the distal portion
- Thickness of the muscle
- Volume of the muscle
- Weight of the muscle

Quite a big difference can be noticed while comparing the average

values in males and females. Thus gender seems to be a discriminatory factor for the above-mentioned qualities. For instance, the incision is supposed to be longer in case of men, as the average value in this group was 23 ± 1.55 cm, whereas in the group of women it was 20.25 ± 0.50 cm (Table 4).

Thickness of the muscle may be expected to influence the presence of the vascular division. In individuals with the division, the values of the thickness of the muscle (6.67 ± 1.15) were higher on average than in those where the division did not occur (1.13 ± 0.29).

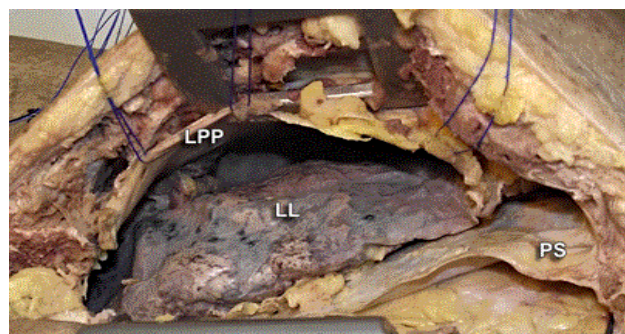


Figure 19: LPP – left parietal pleura, LL – left lung, PS – pericardial sac.

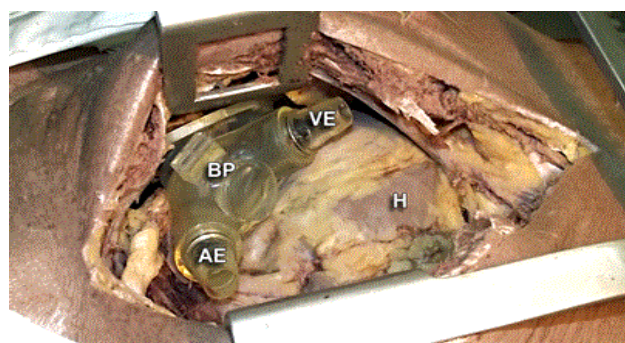


Figure 20: PMi – pectoralis minor muscle, LPP – left parietal pleura, AA – ascending aorta, PT – pulmonary trunk, RAH – right article of heart, LV – left ventricle, RV – right ventricle.

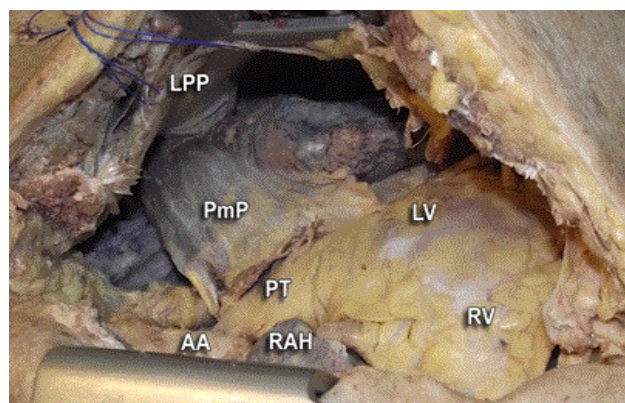


Figure 21: BP – bio-pump, H – heart, VE – ventricular end, AE – aortal end.

	N	Mean	Median	Mode	Min	Max	SD
Weight [kg]	6	85.1667	85.50	Multiple	65.00	105.00	13.87684
Height [cm]	6	173.0000	172.00	172.0000	169.00	179.00	3.79473
Length of hockey-stick incision [cm]	6	23.0000	23.00	Multiple	21.00	25.00	1.54919
Length of pectoralis minor muscle [cm]	6	14.2500	14.25	13.00000	13.00	16.00	1.17260
Width of proximal portion [cm]	6	1.9667	2.00	2.000000	1.50	2.30	0.25820
Width of middle portion [cm]	6	5.5833	5.50	7.500000	3.50	7.50	1.71513
Width of distal portion [cm]	6	9.8333	9.50	9.000000	8.00	12.00	1.47196
Area of triangle [cm ²]	6	67.5350	66.125	Multiple	36.00	96.00	20.70317
Thickness of muscle [cm]	6	1.2000	1.10	1.000000	1.00	1.50	0.24495
Volume of muscle [cm ³]	6	85.0833	74.15	Multiple	36.00	144.00	40.87001
Weight of muscle [g]	6	38.9500	39.00	Multiple	32.40	43.50	3.97329
% of patient's weight	6	0.0460	0.046	Multiple	0.041	0.05	0.00365

Table 2: Descriptive characteristics – men.

	N	Mean	Median	Mode	Min	Max	SD
Weight [kg]	4	57.00	58.00	58.00	52.00	60.00	3.464102
Height [cm]	4	165.75	166.50	168.00	162.00	168.00	2.872281
Length of hockey-stick incision [cm]	4	20.25	20.00	20.00	20.00	21.00	0.500000
Length of pectoralis minor muscle [cm]	4	13.50	13.50	Multiple	12.00	15.00	1.732051
Width of proximal portion [cm]	4	1.30	1.40	Multiple	0.70	1.70	0.432049
Width of middle portion [cm]	4	4.125	4.25	4.50	3.50	4.50	0.478714
Width of distal portion [cm]	4	7.50	8.00	8.00	6.00	8.00	1.000000
Area of triangle [cm ²]	4	50.25	48.00	48.00	45.00	60.00	6.652067
Thickness of muscle [cm]	4	0.825	0.80	0.80	0.70	1.00	0.125831
Volume of muscle [cm ³]	4	41.25	41.70	Multiple	33.60	48.00	6.487681
Weight of muscle [g]	4	27.725	27.75	Multiple	25.40	30.00	1.975475
% of patient's weight	4	0.0485	0.049	Multiple	0.046	0.05	0.001727

Table 3: Descriptive characteristics – women.

	N	Mean	Median	Mode	Min	Max	SD
Weight [kg]	7	76.1429	76.0000	58.00000	58.0000	105.0000	17.27646
Height [cm]	7	170.4286	170.0000	Multiple	162.0000	179.0000	5.91205
Length of hockey-stick incision [cm]	7	21.8571	22.0000	Multiple	20.0000	24.0000	1.67616
Length of pectoralis minor muscle [cm]	7	14.0714	14.5000	Multiple	12.0000	16.0000	1.42678
Width of proximal portion [cm]	7	1.7143	2.0000	2.000000	0.7000	2.3000	0.53363
Width of middle portion [cm]	7	5.2143	4.5000	Multiple	3.5000	7.5000	1.62934
Width of distal portion [cm]	7	9.0000	9.0000	Multiple	6.0000	12.0000	2.00000
Area of triangle [cm ²]	7	61.1729	58.5000	Multiple	36.0000	96.0000	21.38198
Thickness of muscle [cm]	7	1.1286	1.0000	1.000000	0.7000	1.5000	0.29277
Volume of muscle [cm ³]	7	74.1571	58.5000	Multiple	33.6000	144.0000	43.86688
Weight of muscle [g]	7	35.2714	37.5000	Multiple	27.0000	43.5000	6.12365
% of patient's weight	7	0.0466	0.0470	Multiple	0.0410	0.0500	0.00349

Table 4: Descriptive characteristics – division = 0.

Conclusions

1. Taking into consideration the position of the muscle, orientation of its fibers and the sources of the vascular distribution (having a direct influence on the possibility of mobilizing the muscle), it has been concluded that the left pectoralis minor muscle is the muscle of choice to serve as a power source to a new prototype of a bio-pump.

2. The vascular pedicle as well as the presence of single long blood vessels make it possible to mobilize the muscle within the range from 3 to 5 cm.

3. The presence of the connective tissue attachments facilitates fixing the muscle to the second or third rib and to the bio-pump.

4. The direction of muscle fibers corresponds with the axis of the muscular activity.

The pectoralis major muscle due to the transverse orientation of the vascular fascicle and the anatomical arrangement of the fibers seems more suitable for dynamic cardiomyoplasty as well as the latissimus dorsi muscle, and due to the flat and thin muscular layer.

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