DIRECT MEASUREMENT OF THE SKELETAL MUSCLE TONUS

Valenčič, V.

Edvard Kardelj University of Ljubljana
Faculty of Electrical and Computer Engineering
Ljubljana, YUGOSLAVIA

ABSTRACT

A simple method for direct measurement of the muscle tonus has been developed. The measurement device is based on professional dc-dc magnetic displacement sensor. The proportionality of the proposed method has been tested according to the measurements of the moment with three-dimensional coordinte brace in isometric condition. Dynamic responses of the ankle joint moments have been compared to traces of the tibialis anterior muscle belly radial displacement. The method has been performed on five healthy subjects, four patients with denervated pretibial muscle group, and on muscle dystrophy patient. The muscle contractions have been elicted with the twitch and tetanic electrical stimulation and volitional control as well. Distinction and correlation of both measurement methods have been analysed.

KEY WORDS: biomechanics, skeletal muscle, tonus, dynamics, stimulation.

INTRODUCTION

Responses of the skeletal muscles due to various external stimulus have been primarily measured in order to assess the effects of the therapeutic or orthotic funct9ional stimulation [1,2,3]. Dynamic responses of the muscle contraction have been extensively studied for parameter identification of the ankle joint biomechanical models [4,5]. In patients with some denervated muscles groups and in patients affected by neuromuscular diseases i.e. progressive muscular dystrophy the unbalance of the agonistic and antagonistic muscles force occurred [6]. Usually the antagonistic muscles group - m.soleus and m. gastrocnemius are less affected due to progression of the disease than agonistic muscles of the shank - m. tibialis anterior, m. extensor digitorum longus, m. peronaeus brevis. If torque measurement of the ankle joint is performed, the records represent results which are combination of the agonistic and antagonistic muscles force elicited by electrical stimulation of the pretibial muscle group. This muscle group is stimulated usually in order to improve motor dysfunction.

The selectivity of the stimulation by means of the surface bipolar electrodes is not satisfactory, particularly if the stimulation in children affected by muscular dystrophy is applied. This method of the treatment changes the property of the pretibial muscle group [7]. If our coordinate brace measurement system is used, instead of desired torques in direction of the dorsiflexion, a torque in direction of the plantar flexion is often recorded. Assessments of the target muscles group characteristics often is not accomplished adequately. Therefore a new measurement system has been developed in order to solve some problems of nonselective detection of the particular muscle or muscle group contraction.

Characteristics of systems			
	Quantity		
	Moment force	Position joint angle	Displacement Pressure
	Unit		
CRITERIA	Nm,N	m,rad	m,Pa
Directness	no	no	yes
Selectiveness	no	no	yes
Isometric measurement	yes	no	yes
Isotonic measurement	no	yes	yes
Isocinetic measurement	conditionaly	conditionaly	conditionaly
Absolute quantity	yes	conditionaly	conditionaly
Simplicity	simple	medium	simple
Calibration	simple	medium	difficult
Cost of development	high	medium/high	medium
Cost of purcase	high	medium/high	medium

Table 1: The various methods comparison for measurements of the biomechanical characteristics of neuro-muscular systems in man.

COMPARISONS OF VARIOUS MEASUREMENT METHODS

Biomechanical characteristics of skeletal muscles can be measured by means of three different physical quantities:

- *force, moment with isometric or isokinetic brace, force plate, force shoes;*
- *joint angle, position with goniometers, TV systems;*
- *displacement, pressure with displacement or pressure sensors.*

The main attributes of various measurement systems for assessment of biomechanical characteristics of skeletal muscles are summarized in table 1.

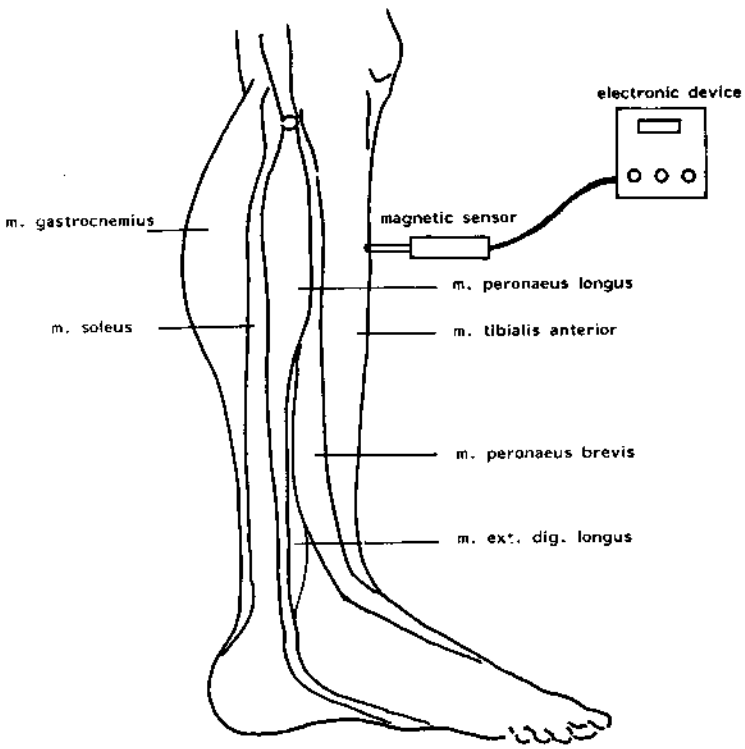

Figure 1: The principle of the muscle tonus measurement system based on precision dc-dc displacement transducer.

Estimations of the qualitative characteristics above are estimated by the involvement of the Ljubljana research team. Since 1973 various systems have been developed, used and evaluated in our laboratories.

Directness and selectiveness are the most important relative advantages of muscle tonus displacement measurement system (MTD). Pressure or displacement sensors are directly positioned on the muscle belly and therefore influence of accompanied biomechanical structures have less effect to the measurement results. The major disadvantage is the lack of absolute force or momentum measurement of segments of the extremities. The calibration of the device is also delicate. The aim of this work is the presentation of relations between the muscle belly displacement and the momentum measurement system.

MEASUREMENT SYSTEM DESIGN

The principle of the measurement is shown in Fig. 1. The crucial part of the measurement system is professional dc-dc displacement transducer model #0353-000 made by Trans-Tek Incorporated. The maximum nonlinearity of the transducer is 0.300% of full scale. The sensitivity is 1.120 V/Inch/Volt Input, Working range is ±0.5 inch(es).

The transducer is mechanically constructed on heavy support with apparatus for precise positioning of the transducer directly to belly of the muscle. This transducer originally includes a spring which produces the pressure to the surface of the muscle belly. Maximum backward force is 4.2 N.

Original moving point of the sensor was substituted with a round replaceable disk 8 mm in diameter.

The transducer is connected with electronic apparatus which includes power supplies, amplifier with possibility to adjust the range of amplification to value of 1, 10 and 100 times. Initial offset adjustment is also possible. Digital display shows displacement of the sensor point from initial position directly in mm. There are two output connectors; the first one is direct signal from transducer, and the second one is amplified signal reduced for initial offset.

In this way both initial positions and displacement of the sensor are available for further signal processing by computer or simply analog recording.

EVALUATION OF MUSCLE TONUS MEASUREMENT SYSTEM

Before the proposed measurement technique was introduced as a routine method, it had been tested on various criteria:

- *Relation between muscle tonus and momentum of the ankle joint evaluation.*
- *Initial displacement and pressure of the sensor determination.*
- *Dynamic response explanation and reasonable model designl.*
- *Position of the sensor optimisation*
- *Muscle belly or tendon.*
- *Various muscles or muscles groups testing.*

At the first stage of testing pretibial muscle group was chosen because suitable ankle joint brace is available in our laboratory. Measurements of the ankle joint momentum have been used for several years as a standrad device for assessments of the effects of therapeutic or orthotic treatment on lower leg. The records obtained by measurement device have been compared with the records of the ankle joint brace.

Relations between muscle tonus and momentum of the ankle joint have been analysed in three ways:

- *Twitch contractions elicited by single electrical impulses.*
- *Tetanic contractions elicited by electrical stimulation.*
- *Volitional contractions.*

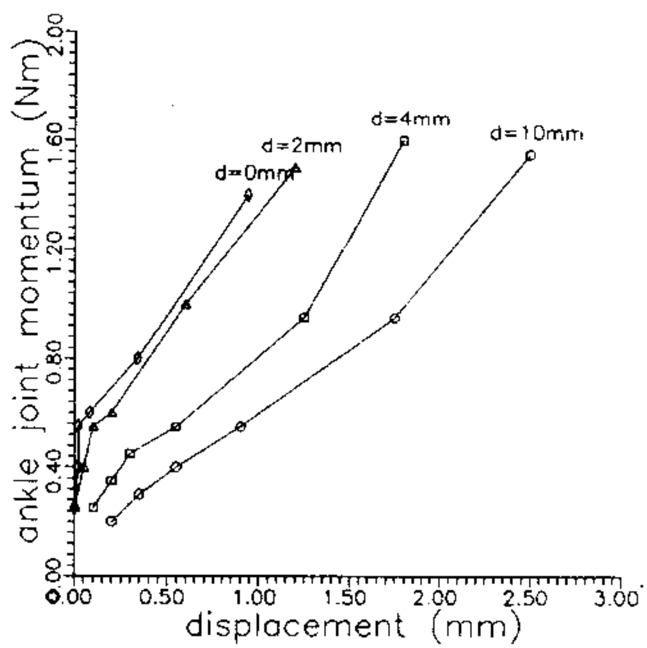

Figure 2: Relationship between ankle joint momentum and displacement of tib. ant. muscle belly in the case of twitch stimulation and various initial displacement in the range of d=0 mm to 10 mm. Labelled points represent records at 40,50,60,70,80 and 90V from minimal to maximal response, respectively.

Subject was seated comfortably in the measurement chair. Displacement sensor was poisitioned on the belly of the m. tibialis anterior at the surface where the maximal enlargement of the belly was observed. This position needed to be determined individually because of variability of anatomy. Initial displacement of the sensor was adjusted in the range of 0 to 10 mm. Bipolar electrodes 16 cm^2 were positioned to elicit maximal contraction of the pretibial muscle group. Anode was positioned proximally.

The first test was twitch contractions with pulse width 1ms. Voltage was adjusted in range from 40V to 90V in steps of 10V. The impulses were generated by a Grass S88 stimulator with isolation unit.

From the Figure 2 there is evident a proportionality of the displacement and the ankle joint momentum. Better results were obrained if the initial displacement was adjusted to 10 mm. Nonlinearity of the relationships was more significant at the extremely low responses, and was less than 0.5 Nm when both of the measurement systems are not accurate.

Figure 3 shows the records obtained in a healthy subject (left) and records of a subject with motor dysfunction of pretibial muscle group due to denervation of the peroneal nerve (right). The above records are momentums of ankle joints and the records below are obtained by displacement measurement system. It is evident that the record of momentum on the right is biphasic due to combined activity of agonistic and antagonistic groups of muscles.

A selective assessment of denervated and therefore weaker agonistic muscle groups is not possible by using only ankle joint measurement system. This example shows the advantage of the proposed displacement measurement device, compared to the ankle joint measurement method.

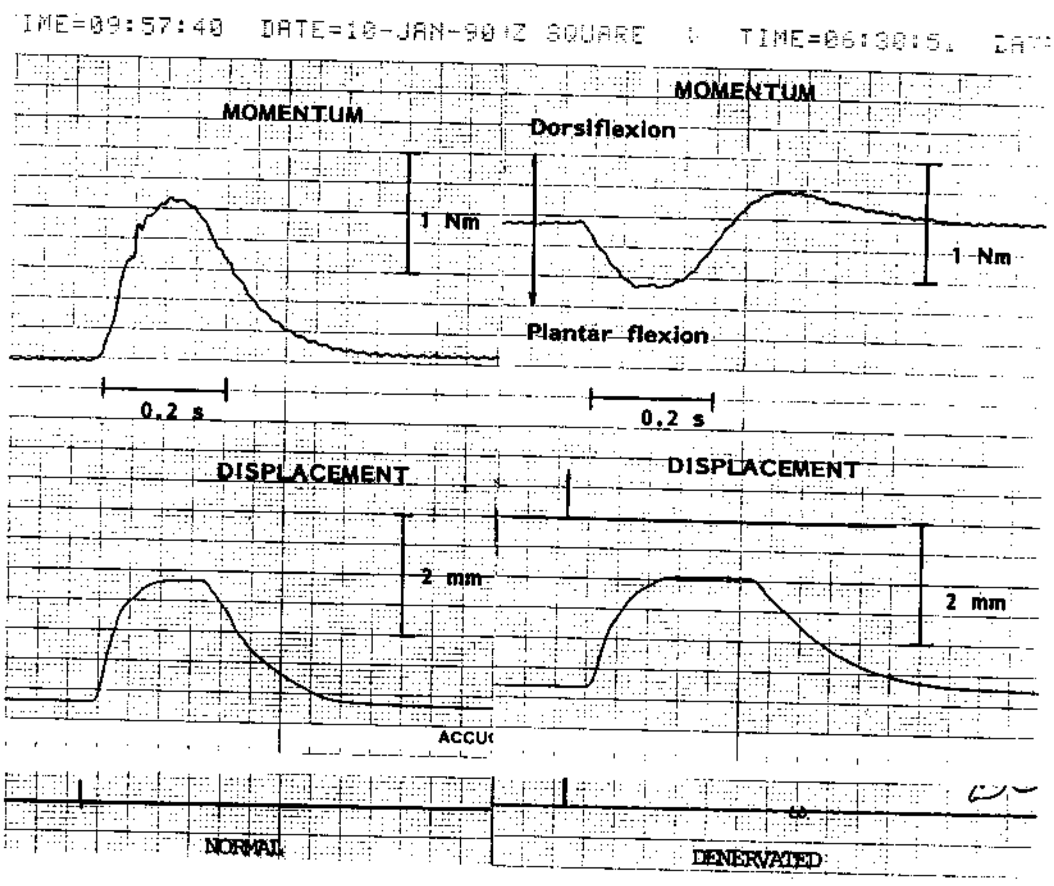

Figure 3: Dynamic responses of the m. tibialis anterior twitch stimulation 91ms,80V) measured by ankle joint momentum measurement system (figures above) and records obtained by muscle tonus displacement measurement system (figures below). Records obtained in a healthy subject are on the left side, and records of a subject with motor dysfunction of pretibial muscle group due to denervation of the peroneal nerve are on the right side of the figure. It is evident the advances of proposed measurement system.

Similar results were obtained if healthy subjects were tested by tetanic stimulation. Pulse width was 0.3 ms and frequency was 40 Hz. Amplitude of stimuli varied in the range from 40 to 90 V in 10 V steps.

Records of the ankle joint momentum are shown on the above part of Figure 4. Records of the displacement are shown on the below part of Figure 4. The momentum is proportional to the amplitude up to 60 V. If amplitude is increased, the momentum is decreased due to coactivation of antagonistic group of muscles. In he contrary,

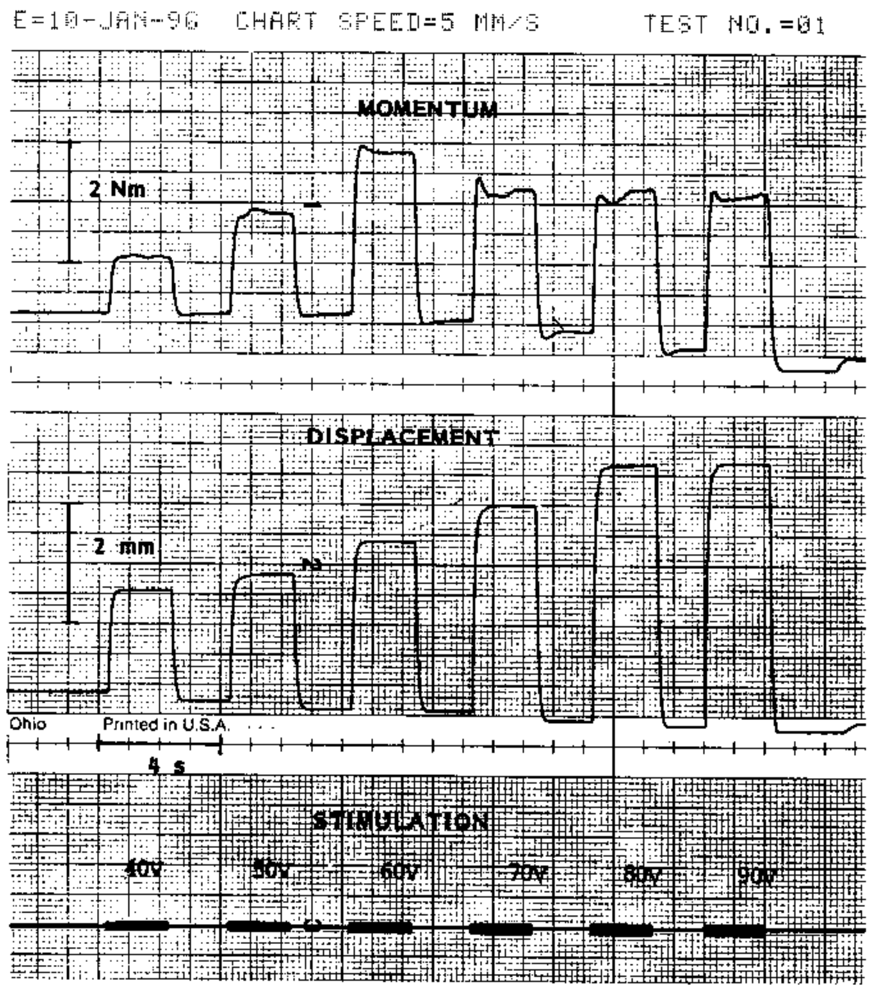

Figure 4: Responses of the m. tibialis anterior tetanic stimulation (0.3ms, 40Hz, amplitude from 40 to 90V) measured by the ankle jont momentum measurement system (figures above) and records obtained by the muscle tonus displacement measurement system (figures below).

contraction of the agonist measured selectively by MTD system is proportional to the amplitude up to 90 V.

These observations demonstrate selectively of the proposed method. The selectivity is improved because measurement of the muscle tonus is more direct than measurement of the ankle joint momentum.

Set of tests has been accomplished with measurement of the volitional elicited contractions of dorsiflexors up to 20 Nm. Ankle joint momentum and muscle tonus have been recorded simultaneously. The was force slowly increased by subjects. They reached the maximal momentum in approximately 4 seconds. Traces of both signals were recorded on Brush analog recorder.

Initial displacements were 10 mm and the diameter of sensor was 8 mm. This diameter was found as optimal in a subsequent test.

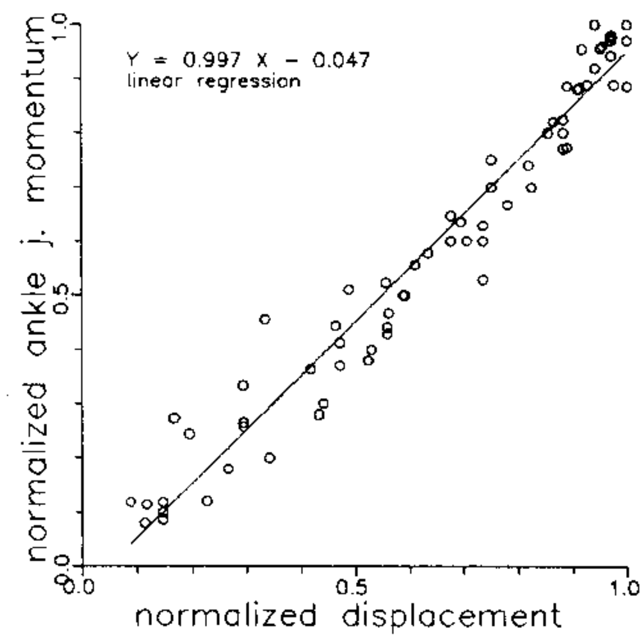

Figure 5: Scatterogram and regression line of the relationship between normalised ankle joint momentum and normalised tonus elicited by volitional contraction of dorsiflexors. Illustration above demonstrates a high correlation of both records in the whole range of volitional contraction if measurements are applied in healthy subjects.

Results are normalized to the maximum and are plotted in Figure 5. Linear regression line was calculated and is represented by the equation 1.

$$y=0.997x-0.047 \quad (1)$$

where y is normalized ankle joint momentum and x is normalized muscle tonus measured by displacement of the muscle belly.

DISCUSSION AND CONCLUSIONS

The analysis above demonstrates the comparison between two techniques for the assessment of the motor dysfunctions of skeletal muscles. The first technique is the ankle joint momentum measurement and the second is a new technique for direct measurement of the muscle tonus with precision electromagnetic displacement sensor.

This preliminary study shows the possibilities for direct and selective measurements of biomechanical characteristics of skeletal muscles. Proportionality of the records attained by both techniques is acceptable in full range of contraction force. The major advantages of the proposed system are:

- *Directness of response.*
- *Selectiveness to particular muscle group.*
- *Reasonable cost of the system.*
- *Usefulness in patients with extremely severre motor dysfunctions i.e. denervation, progressive muscular dystrophy, spinal amiothrophy.*
- *Applicability to all muscles or muscle groups which are completely or partially within reach from the surface of the body without significant adaptation or rebuilding of measurement device.*
- *Usefulness for various neurological vibration tests while other standard electrophysiological test failed because of stimulus artifacts.*
- *Suitability for dynamic responses recording due to external applied stimuli.*

In this stage of the research a new technique has been proposed. Design of the device has been accomplished. Device has been tested on precision and accuracy.

It was found that the shapes of dynamic responses measured by mechanical brace and by MTD system differ consistently. Namely, in all records obtained by MTD system a plateau at the top of response occured, what was not observed in dynamic responses which were measured by mechanical brace. Shapes of the records can be compared on Figure 3. These new observations are interesting while the records represent the characteristics of the skeletal muscle contraction in the radial direction. At the present we have not an acceptable explanation for the phenomena detected by proposed system. Additional research will be continued, and appropriate model should be created by succeeding study.

Acknowledgements: This work was supported by the Slovene Research Community, Ljubljana, by the NIDRR Washington, D.C. and Slovene association for neuromuscular disease. In various phases this project was assisted by Prof. Lojze Vodovnik, Miran Kogovšek Eng., Jože Šafranič Eng., Peter Krošelj Dipl.Eng. and Nataša Kogovšek senior student.

REFERENCES

1. L. Vodovnik, "The dynamic response of a musculosceletal system due to electrical stimulation", Report EDC, no.4, pp.64-74, 1964.

2. L.Vodovnik and A.Stefanovska, "Restorative and regenerative functional electrical stimulation", in Proceedings of International Workshop on FNS Osaka, Japan, pp.11-27,1989.

3. E.Marsolais and R.Kobetic, "Implantation techniques and experience with percutaneous intramuscular electrodes in the lower extremities", J.Rehab.Res.Develop. 23, no.23,pp.1-8,1986.

4. S.Reberšek and L.Vodovnik, "Biomehanski model gle'nja", in Proceedings of JUREMA, Zagreb, pp. 86-87, 1982.

5. V.Valenčič, S.Reberšek, L. Vodovnik, M. Štefančič, A. Stefanovska, T. Jelnikar, and M. Kogovšek, "Dynamic model of normal and denervated muscles in man", in Proceedings of the Eighth International Symposium on ECHE, Belgrade, pp. 147-158, 1984.

6. V.Valenčič, A. Jerčinović, L. Vodovnik, A. Zupan, M. Gregorič, and I. Tomšič, "A two-dimensional mathematical model of stimulated agonistic and antagonistic pair of sceletal muscles group", in Proceedings of V Mediterranean Conference on Medical and Biological Engineering, Patras, pp. 150-151, 1989.

7. G.Vrbova and K. Ward, "Observation on the effects of low frequency electrical stimulation on fast muscles of dystrophic mice", J. of Neurology, Neurosurgery, and Psyhiatry, vol. 44, pp. 1002-1006, 1981.

REFERENCES

1. L. Vodovnik, "The dynamic response of a musculosceletal system due to electrical stimulation", Report EDC, no.4, pp.64-74, 1964.

2. L.Vodovnik and A.Stefanovska, "Restorative and regenerative functional electrical stimulation", in Proceedings of International Workshop on FNS Osaka, Japan, pp.11-27,1989.

3. E.Marsolais and R.Kobetic, "Implantation techniques and experience with percutaneous intramuscular electrodes in the lower extremities", J.Rehab.Res.Develop. 23, no.23,pp.1-8,1986.

4. S.Reberšek and L.Vodovnik, "Biomehanski model gle'nja", in Proceedings of JUREMA, Zagreb, pp. 86-87, 1982.

5. V.Valenčič, S.Reberšek, L. Vodovnik, M. Štefančič, A. Stefanovska, T. Jelnikar, and M. Kogovšek, "Dynamic model of normal and denervated muscles in man", in Proceedings of the Eighth International Symposium on ECHE, Belgrade, pp. 147-158, 1984.

6. V.Valenčič, A. Jerčinović, L. Vodovnik, A. Zupan, M. Gregorič, and I. Tomšič, "A two-dimensional mathematical model of stimulated agonistic and antagonistic pair of sceletal muscles group", in Proceedings of V Mediterranean Conference on Medical and Biological Engineering, Patras, pp. 150-151, 1989.

7. G.Vrbova and K. Ward, "Observation on the effects of low frequency electrical stimulation on fast muscles of dystrophic mice", J. of Neurology, Neurosurgery, and Psyhiatry, vol. 44, pp. 1002-1006, 1981.