# Journal of Medical Sciences

ISSN 1682-4474

science alert

ANSInet
an open access publisher
http://ansinet.com

Research Paper

*JMS (ISSN 1682-4474) is an International, peer-reviewed scientific journal that publishes original article in experimental & clinical medicine and related disciplines such as molecular biology, biochemistry, genetics, biophysics, bio-and medical technology. JMS is issued eight times per year on paper and in electronic format.*

*For further information about this article or if you need reprints, please contact:*

Ferruh Taspinar
Department of Physiotherapy, and Rehabilitation,
Dumlupinar University School of Health, Kutahya, Turkey

ANSInet
Asian Network for Scientific Information

J. Med. Sci., 11 (7): 274-279
1st October, 2011
DOI: 10.3923/jms.2011.274.279

# Evaluating the Effects of Different Strength Training Techniques on Anthropometric Structure and Endurance of Healthy Quadriceps Femoris Muscle

[1]Ferruh Taspinar, [2]Ummuhan Bas Aslan and [1]Betul Taspinar

This study was planned to examine the effect of superimposed, resistance exercise and electrical stimulation of the 3 different training on anthropometric characteristics and endurance of healthy quadriceps femoris muscle in untrained healthy young adults. Forty eight untrained healthy young subject aged between 21-26 (22.43±1.12) participated the study. Subjects were divided into 3 groups: Resistance Training Group (RTG) (n = 17); Electrical Stimulation Group (ESG) (n = 15) and Superimposed Training Group (STG) (n = 16). Dominant leg was determined by the selected tests and training was given three times a week for 6 weeks. Knee circumference, thigh circumference, skinfold measurements, repetition of 10-pound work, step-up, step-down an squatting on one leg test of subjects were taken pre-post training. The results indicated that electrical stimulation was not sufficient alone to strengthen the quadriceps femoris muscle. It is thought that training programs including voluntary muscle contraction must be main component of rehabilitation for muscle hypertrophy. In addition, resistance training has been effective in reducing adipose tissue.

**Key words:** Quadriceps femoris, superimpose, endurance, electrical simulation, anthropmetric

[1]Department of Physiotherapy and Rehabilitation, Dumlupinar University School of Health, Kutahya, Turkey
[2]Pamukkale University, School of Physical Therapy and Rehabilitaion, Denizli, Turkey

## INTRODUCTION

The knee joint is the largest and most complex joint in the human body (Mesfar and Shirazi-Adl, 2005). The primary function of the quadriceps femoris muscle is to generate knee extensor torque and stabilize the patella. Muscular weakness is related to many of the musculoskeletal disorders (Pollock and Wilmore, 1990). Muscular weakness in association with quadriceps inhibition has been implicated in the development of functional and structural changes of the knee joint in some knee pathologies such as patellofemoral pain (Sakai *et al*., 2000) and tibio-femoral osteoarthritis (OA) (Hurley and Scott, 1998; Hurley, 1997). Resistive training has been widely used for muscle strengthening in the field of rehabilitation and sports (Waysweher and Webb, 1995). This effect is due to de novo synthesis of contractile proteins resulting in skeletal muscle hypertrophy and neural adaptations, mainly through enhanced motor drive (Enoka, 1997).

Electrical stimulation and resistance exercise are also commonly used by physical therapist in muscle strength rehabilitation. In recent years, they have also been used by athletes in the context of training program to develop strength and physical performance (Paillard *et al*., 2005; Maffiuletti *et al*., 2002). Recently, resistive training and electrical stimulation that are described as Superimpose electrical stimulation technique have been used together (Paillard *et al*., 2005). This technique is not used as widely as resistive training and electrical stimulation separately. Moreover, it is shown that the results of the studies in which the effect of superimpose technique on muscle function is evaluated are contradictory (Pollock and Wilmore, 1990). Therefore, this study was planned to examine the effect of superimposed, resistance exercise and electrical stimulation of the 3 different training on anthropometric characteristics and endurance of healthy quadriceps femoris muscle in untrained healthy young adults.

## MATERIALS AND METHODS

**Subjects:** This study was carried out in Pamukkale University, School of Physical Therapy and Rehabilitation. The subjects were fifty-seven (26 female and 31 male) undergraduate physical therapy students at ages ranging from 21 to 26. Forty-eight students completed all testing procedures and strength training program. Physical characteristics of the participants were presented in Table 1.

No subjects had a history of systemic disease, muscular or neural deficits or knee pathology. They were randomized into three strength training groups. Strength training was given to the subjects' dominant side quadriceps femoris muscle 3 days a week for 6 weeks. All subjects agreed to participate and signed a consent form outlining the procedure. The subjects dealing with sportive activity and exercises regularly were excluded. Those who met inclusion criteria avoided from sportive activities and strength methods during training period.

**Outcome measures:** Subjects performed tests including QF muscle endurance and anthropometric measurements were taken two or three days prior to the beginning of the training program to establish baseline data. Post-measurements were performed on the day two or three following the completion of the strength programs. In the current study, strength training was performed on dominant side QF muscle. Dominant lower extremity of the subjects was defined as the preferred leg used for single-legged jumps (Hass *et al*., 2003).

**Calliper measurements:** Saehan Skinfold Calliper was used to measure the skinfold thickness at erect position while the body weight was on the foot on which the measurement wasn't done. The knee of the extremity on which the measurement was done was semi flexed with the foot touching the floor loosely. The midpoint between the hip joint and superior border of patella having already

Table 1: Total demographic values of the subjects in the groups

| | REG (n = 17) | | ESG (n = 15) | | SIG (n = 16) | | Total (n = 48) | |
|---|---|---|---|---|---|---|---|---|
| Variables | Min-maks. | Mean±SD | Min-maks. | Mean±SD | Min-maks. | Mean±SD | Min-maks. | Mean±SD |
| Age (year) | 21-24 | 22.64±0.86 | 21-23 | 21.86±0.63 | 21-26 | 22.75±1.52 | 21-26 | 22.43±1.12 |
| Height (cm) | 155-184 | 170.29±10.04 | 156-183 | 169.73±9.61 | 155-184 | 170.37±8.76 | 155-184 | 170.14±9.29 |
| Weight (kg) | 40-90 | 62.82±15.26 | 40-105 | 64.26±16.30 | 50-83 | 65.71±10.88 | 40-105 | 64.23±14.06 |
| BMI (kg cm$^{-2}$) | 16.22-31.35 | 22.02±3.78 | 15.63-27.44 | 21.36±3.29 | 19.03-26.53 | 22.50±2.30 | 15.63-31.35 | 21.95±3.14 |
| Variable | | n (%) | | n (%) | | n (%) | | n (%) |
| **Gender** | | | | | | | | |
| Female | | 8 (47.1) | | 8 (53.3) | | 7 (43.8) | | 23 (47.9) |
| Male | | 9 (52.9) | | 7 (46.7) | | 9 (56.2) | | 25 (52.1) |
| **Dominant leg** | | | | | | | | |
| Right | | 16 (94.1) | | 10 (66.7) | | 12 (75.0) | | 38 (79.2) |
| Left | | 1 (5.9) | | 5 (33.3) | | 4 (25.0) | | 10 (20.8) |

ESG: Electrical Stimulation Group, REG: Resistive Exercises Group, SIG: Superimpose Group, X: Mean, SD: Standard Deviation, BMI: Body Mass Index been determined, the calliper measurement was conducted from this point with three repetitions and the mean was recorded in mm (Otman *et al.*, 1995). A fourth measurement was done because a difference more than 2 mm had been found (Heyward, 1998).

**Circumference measurements:** From three areas-knee joint, 5 and 15 cm over superior border of patella, measurement was done at erect position with feet 10 cm apart and body weight shared by the two feet equally (Otman *et al.*, 1995).

**Constant repetition on weight:** After the subjects were positioned on Vectra 4800 ON-LINE (USA) exercise station for measurement on the dominant extremity with their backs supported and their hip and knee at 90° flexion, they were trained with constant 10 p weight with repetition until fatigue and the number of repetition was recorded (Baskan, 2004).

**Step-up and step-down tests:** The subjects were instructed to step up (isotonic contraction) and step-down (eccentric contraction) successively a platform of 45 cm height with repetition until fatigue and the number of repetition was recorded.

**Squatting on one leg test:** This test which evaluates whether there is a functional limitation was used to measure extremity extensor muscle strength. The subjects were instructed to kneel with the body weight repeatedly until fatigue on one leg with the other in flexion without touching the floor and the results were recorded (Ergun and Baltaci, 1997).

**Strength training groups:** In this present study, subjects were divided into three strength training groups including Resistive Exercise Group (REG) (n = 17), Electrical Stimulation Group (ESG) (n = 16) and Superimpose Technique Group (SIG) (n = 16). The groups received strength training three times a week for 6 weeks (Carroll *et al.*, 1998). Ten sec contractions were performed, with a 50 sec resting intervals between contractions in all training procedures. One set included ten contractions. Subjects trained with two sets per session with 5 min resting period between the sets (Koryak, 2004).

Subjects in the REG were seated on the leg press with the hip at 110 degrees flexion and the knee at 100 degrees flexion. They were asked knee flexion from 100 degrees to full extension. 1 RM was determined per two weeks. Training weight was changed on the range 60-80% of their 1 RM (Reeves *et al.*, 2006).

QF muscle of the subjects in the ESG was stimulated by using Endomed 582 stimulator. Russian electrical stimulation procedure (wave form: sinusoidal or triangular, frequency: 2500 Hz, modulation: 50 Hz) was applied to the subjects who were seated in a custom built chair with the hip and knee secured at approximately 90 degrees of flexion. Before the recording of the electrical potential of the QF muscle, the skin was cleaned with 70% alcohol and the electrodes were fixed to the skin with velcro tape. Distal electrode was positioned as transverse 4 cm from the superomedial border of the patella. Proximal electrode was positioned as longitudinally 15 cm from the inferolateral border of the SIAS (Leroux *et al.*, 1997; Parker *et al.*, 2003; Serrao *et al.*, 2005). Prior to applying ES to the subjects, the sensation characteristics of Russian ES, such as light tingling, pin prickling and crushing pain, were described to each subject. Until obtaining muscle contractions, the current was increased. A 0 to 10 Visual Analogue pain Scale (VAS) ranging from "no pain" to "excruciating pain" was introduced to each subject. The subject was instructed to notify the investigator when he or she felt a perception of pain of at least 8 of 10 on the scale for each stimulation (Mcloda and Carmark, 2000).

Electrical stimulation was performed together with resistive voluntary exercises on the subjects in the superimpose group; that is, the training procedure of SIG combined the procedures of REG and ESG.

**Statistical analysis:** All measurements on the training groups were performed pre and post-training. All statistical analyses were performed using SPSS for windows. Significance was accepted at $p = 0.05$. Wilcoxon Rank Test was used to determine if significant differences existed between pre and post-training results. Kruscall Wallis Variance Analysis was used to detect differences existing between groups.

## RESULTS

The study was conducted on 48 healthy participants (25 female, 23 male), aged 21-26 (X = 22, 43, SD = 1, 12). The demographic data of the subjects are presented in Table 1.

None of the pre-training scores were significantly different among the three training groups (Table 2). Significant increase was determined in circumference measurements at 5 cm over superior border of patella for superimpose group and at 15 cm over superior border of patella for resistive exercise group ($p<0.05$) while no increase was found in ESG. Similarly, significant difference was determined in calliper measurements for

Table 2: Comparison of pre-training data of strengthening exercises groups

| | Training groups | | | |
|---|---|---|---|---|
| Variables | ESG (n = 15) | DEG (n = 17) | SEG (n = 16) | p-value |
| Skinfold measurement | 16,33±3.99 | 15.05±5.58 | 16.43±6.41 | 0.587 |
| **Circumference measurements** | | | | |
| Knee circumference | 38.43±4.26 | 37.41±3.44 | 37.37±1.90 | 0.762 |
| Superior border of patella over 5 cm | 41.93±5.75 | 40.20±3.86 | 40.87±2.54 | 0.769 |
| Superior border of patella over 15 cm | 49.40±6.51 | 47.38±4.85 | 48.96±3.10 | 0.469 |
| Constant repetition on weight | 32.40±25.55 | 39.58±32.29 | 34.87±23.91 | 0.717 |
| Step-up test | 34.86±18.77 | 46.76±22.30 | 47.43±27.79 | 0.265 |
| Step-down test | 18.33±11.22 | 23.88±12.77 | 20.43±8.64 | 0.532 |
| Squatting on one leg test | 34.40±13.94 | 39.00±22.71 | 40.50±17.25 | 0.585 |

Values are Mean±SD, ESG: Electrical Stimulation Group, REG: Resistive Exercises Group, SIG: Superimpose Group

Table 3: Before training and after training data of strengthening training groups

| | REG | | | ESG | | | SIG | | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | BT | AT | p-value | BT | AT | p-value | BT | AT | p-value |
| Skinfold measurement | 15.05±5.58 | 14.02±4.98 | 0.004* | 16.33±3.99 | 15.93±3.63 | 0.202 | 16.43±6.41 | 15.43±6.12 | 0.030* |
| **Circumference measurement** | | | | | | | | | |
| Knee circumference | 37.41±3.44 | 37.14±2.79 | 0.388 | 38.43±4.26 | 38.46±4.36 | 0.655 | 37.37±1.90 | 37.50±1.85 | 0.102 |
| Superior border of patella over 5 cm | 40.20±3.86 | 40.26±3.68 | 0.593 | 41.93±5.75 | 42.00±5.44 | 0.774 | 40.87±2.54 | 41.43±2.76 | 0.017* |
| Superior border of patella over 15 cm | 47.38±4.85 | 48.02±4.56 | 0.013* | 49.40±6.51 | 49.53±6.46 | 0.606 | 48.96±3.10 | 49.53±3.64 | 0.121 |
| Constant repetition on weight | 39.58±32.29 | 48.76±37.08 | 0.001* | 32.40±25.55 | 41.33±28.33 | 0.005* | 34.87±23.91 | 49.18±29.97 | 0.000* |
| Step-up test | 46.76±22.30 | 54.05±25.82 | 0.002* | 34.86±18.77 | 46.13±22.53 | 0.001* | 47.43±27.79 | 58.37±30.40 | 0.001* |
| Step-down test | 23.88±12.77 | 27.82±13.56 | 0.002* | 18.33±11.22 | 24.26±14.28 | 0.001* | 20.43±8.64 | 26.12±10.78 | 0.000* |
| Squatting on one leg test | 39.00±22.71 | 52.35±28.47 | 0.000* | 34.40±13.94 | 50.13±15.93 | 0.001* | 40.50±17.25 | 52.81±19.36 | 0.000* |

Values are Mean±SD. BT: Before Training, AT: After Training, cm: centimeter, ESG: Electrical Stimulation Group, REG: Resistive Exercises Group, SIG: Superimpose group, *p<0.05

Table 4: The comparison of post-training data of strengthening exercises groups

| Variables | ESG (n = 15) | DEG (n = 17) | SEG (n = 16) | p-value |
|---|---|---|---|---|
| Skinfold measurement | 15.93±3.63 | 14.02±4.98 | 15.43±6.12 | 0.521 |
| **Circumference measurements** | | | | |
| Knee circumference | 38.46±4.36 | 37.14±2.79 | 37.50±1.85 | 0.756 |
| Superior border of patella over 5 cm | 42.00±5.44 | 40.26±3.68 | 41.43±2.76 | 0.608 |
| Superior border of patella over 15 cm | 49.53±6.46 | 48.02±4.56 | 49.53±3.64 | 0.595 |
| Constant repetition on weight | 41.33±28.33 | 48.76±37.08 | 49.18±29.97 | 0.638 |
| Step-up test | 46.13±22.53 | 54.05±25.82 | 58.37±30.40 | 0.536 |
| Step-down test | 24.26±14.28 | 27.82±13.56 | 26.12±10.78 | 0.693 |
| Squatting on one leg test | 50.13±15.93 | 52.35±28.47 | 52.81±19.36 | 0.896 |

Values are Mean±SD. SG: Electrical Stimulation Group, REG: Resistive Exercises Group, SIG: Superimpose group

both groups, but no difference was found in ESG. However, in all three training groups, a six week training produced significant increments in scores of repetition of 10 pound work, step-up, step down and squatting on one leg test for the three training groups ($p<0.05$). The data obtained from the subjects before and after training are presented in Table 3.

In the present study, also the QF muscle anthropometric and endurance gains in groups were compared. The increase in post-training scores of anthropometric measurements, repetition on 10 pound work test, step up test, step down test, squatting on one leg test of the groups was not statistically different ($p>0.05$) (Table 4). Accordingly, all the techniques caused increments in the QF muscle endurance. While an improvement was determined in anthropometric characteristics and an increase was determined in endurance of training groups involving voluntary muscle contraction, no improvement or increase was found in electric stimulation group.

## DISCUSSION

Our study was carried out to find out the effect of the three different strength training techniques on the anthropometric measurements and endurance of healthy QF muscle and to compare the effect of SI technique, RE and ES technique.

A one-week familiarisation period was given to our subjects prior to evaluation and resistive training. In this period, endurance tests and measurements of the subjects were done at most three trials in three days with 48 h intervals and the last values of the last day were recorded.

Lambert *et al.* (2002) having studied the effects of short period RE applications on muscle performance, indicate that the protocols which have been applied in order to do not affect the results of strength training on the muscle is not supposed to cause fatigue in the muscle. Our subjects were trained with 60-80% values of 1 RM lest any fatigue and complications. During strength training, such complications as muscular spasm and Delayed Onset Muscle Soreness (DOMS) might occur in addition to fatigue. It was revealed that such risk factors were able to be minimized thanks to the exercises not exceeding 10 repetition 2-3 times a week (Feigenbaum and Pollock, 1999). In our study, resistive training was performed at medium intensity in 2 sets with 10 repetitions for 6 weeks and after the subjects attended our strength training program 3 times a week, their anthropometric characteristics enhanced and endurance increased ($p<0.05$).

The most common electrical current in studies to increase muscular strength is via electrical stimulation in Russian current (Nelson *et al*., 1999). Therefore, when ESG were exposed to Russian current in strength training in our study, anthropometric characteristics didn't change but endurance was observed to improve in the ES training. Romero *et al*. (1982) found in their studies on healthy subjects that ES increased isometric muscular strength by 31% ($p<0.05$). Baskan (2004) announced an increase in strength end performance after 6 weeks in subjects exposed to electrical stimulation.

The third training method in our study was SI technique. The subjects who had strength training with this technique were observed to have improved their anthropometric characters and endurance after the training. Strojnik (1995) stated that performance was better when ES was accompanied with jump activities and added that the duration and speed of the jump were affected positively in this combination. As a result, he decided that this technique was effective.

In our study, the thigh skinfold values decreased in resistive exercise after training while an increase was determined in thigh circumference measurement ($p<0.05$). However, no change was found in ESG. O'connor and Lamb (2003), in their study researching the effect of high intensity resistive exercise on body composition and muscle strength of 39 females, exposed 20 of the subjects to strength training program and chose 19 of them as the control group. After a 12-week training, an increase was seen in the strength of study group while a decrease was found in skinfold measurement values taken from 7 different areas of the study group ($p<0.05$).

Willoughby and Simpson (1998) grouped 20 healthy field-sportsmen in 4 groups randomly as ESG, REG, SIG and control group. Subject in REG were exposed to 85% of 1 RM. Their training comprised of 6 weeks-3 times a week with 8-10 repetitions in 3 sets. Before and after the program the QF muscle strength was analysed in 1 RM and vertical jump distance was analysed in centimetres. As a result, in all groups, an increase was observed in strength and jump distances, but SI technique-which means the combination of the two techniques above-was pointed out as the most efficient technique statistically ($p<0.05$) with the most significant increase. In our opinion, the reason why this study concluded that SI technique was efficient was due to the fact that the sample consisted of 3 sets (while ours consisted of two sets).

The SI technique in present study which was performed as a combination of medium intensive RE and Russian ES was found not to be different from other techniques in endurance and anthropometric measurements.

## CONCLUSION

The results of our study showed that electrical stimulation of healthy QF, resistive exercise and superimpose technique improve QF muscle anthropometric characters and endurance but there was no difference among the three groups. In this regard, in the future, more studies on the subject with different loads in RE, with different currents and different sample in ES could be more illustrative and clearer.

## REFERENCES

Baskan, E., 2004. Saglikli quadriceps femoris kasinin kuvvetlendirilmesinde kullanilan yontemlerin karsilastirilmasi. Yuksek Lisans Tezi, Pamukkale Universitesi Saglik Bilimler Enstitusu, Denizli, pp: 122.

Carroll, T.J., P.J. Abernethy, P.A. Logan, M. Barber and M.T. McEniery, 1998. Resistance training frequency: Strength and myosin heavy chain responses to two and three bouts per week. Eur. J. Applied Physiol. Occup. Physiol., 78: 270-275.

Enoka, R.M., 1997. Neural adaptations with chronic physical activity. J. Biomech., 30: 447-455.

Ergun, N. and G. Baltaci, 1997. Spor yaralanmalarinda fizyoterapi ve rehabilitasyon prensipleri. Hacettepe Universitesi Fizik Tedavi ve Rehabilitasyon Yayinlari, Ankara, pp: 224.

Feigenbaum, M.S. and M.L. Pollock, 1999. Prescription of resistance training for health and disease. Med. Sci. Sports Exercise, 31: 38-45.

Hass, J.C., E.A. Schick, J.W. Chow, M.D. Tillman, D. Brunt and J.H. Cauraugh, 2003. Lower extremity biomechanics differ in prepubescent and postpubescent female athletes during stride jump landings. J. Applied Biomech., 19: 139-152.

Heyward, V.H., 1998. Advanced Fitness Assessment and Exercise Prescription. 3rd Edn., Human Kinetcs, USA.

Hurley, M.V. and D.L. Scott, 1998. A clinically applicable exercise regime that decreases disability in knee osteoarthritis. Physiotherapy, 84: 398-398.

Hurley, M.V., 1997. The effects of joint damage on muscle function, proprioception and rehabilitation. Manual Ther., 2: 11-17.

Koryak, Y., 2004. Effects of training with Functional Electrical Stimulation (FES) on ankle joint torque. Proceedings of the 9th Annual Conference of the International FES Societ, September 6-9, 2004, Bournemouth, UK., pp: 74-76.

Lambert, C.P., D.E. Armstrong, D. Jacks, W.J. Armstrong, M.G. Flynn, 2002. Reliability of an exercise protocol designed to evaluate resistance exercise performance. J. Strength Cond. Res., 16: 149-151.

Leroux, A., J.P. Boucher, G. Poumarat, 1997. Investigation of quadriceps femoris function through electrical stimulation. J. Athletic Train., 32: 115-118.

Maffiuletti, N.A., M. Pensini and A. Martin, 2002. Activation of human plantar flexor muscles increases after electromyostimulation training. J. Appl. Physiol., 92: 1383-1392.

Mcloda, T.A. and J.A. Carmark, 2000. Optimal burst duration during a facilitated quadriceps femoris contraction. J. Athletic Training, 35: 145-150.

Mesfar, W. and A. Shirazi-Adl, 2005. Biomechanics of the knee joint in flexion under various quadriceps forces. Knee, 12: 424-434.

Nelson, R., K. Hayes and D. Currier, 1999. Clinical Elektrotheraphy. Appleton and Lange, New York, pp: 143-182.

O'connor, T.E. and K.L. Lamb, 2003. The Effect of bodymax high-repetation resistance training on measures of body composition and muscular strength in active adult women. J. Strenght Cond. Res., 17: 614-620.

Otman, S., H. Demirel and A. Sade, 1995. Tedavi hareketlerinde temel degerlendirme prensipleri. Hacettepe Universitesi Fizik Tedavive Rehabilitasyon Yayinlari, Ankara, pp: 49-57.

Paillard, T., F. Noe, P. Passelergue and P. Dupui, 2005. Electrical stimulation superimposed onto voluntary muscular conraction. Sports Med., 35: 951-966.

Parker, M.G., M.J. Bennett, M.A. Hieb, A.C. Hollar and A.A. Roe, 2003. Strength response in human quadriceps femoris muscle during 2 neuromuscular electrical stimulation programs. J. Orthopeaedic Sports Phys. Ther., 33: 719-726.

Pollock, M.L. and J.H. Wilmore, 1990. Exercise in Health and Disease: Evaluation and Prescription for Prevention and Rehabilitation. 2nd Edn., WB Saunders, Philadelphia, Pages: 760.

Reeves, N.D., M.V. Narici and C.N. Maganaris, 2006. Musculoskeletal adaptations to resistance training in old age. Man Ther., 11: 192-196.

Romero, J.A., T.L. Sanford, R.V. Schroeder and T.D. Fahey, 1982. The effects of electrical stimulation of normal quadriceps on strength and girth. Med. Sci. Sports Exerc., 14: 194-197.

Sakai, N., Z.P. Luo, J.A. Rand and K.N. An, 2000. The influence of weakness in the vastus medialis oblique muscle on the patellofemoral joint: An *in vitro* biomechanical study. Clin. Biomech. (Bristol, Avon)., 15: 335-339.

Serrao, V.F., C.M. Cabral, F. Berzin, C. Candolo and V.M. Pedro, 2005. Effect of tibia rotation on the elektromyographical activity of the vastus medialis oblique and vastus lateralis longus muscles during isometric leg press. Phys. Ther. Sport, 6: 15-23.

Strojnik, V., 1995. Muscle activation level during maximal voluntary effort. Eur. J. Applied Physiol. Occup. Physiol., 72: 144-149.

Waysweher, H. and G. Webb, 1995. Therapeutic Exercise in Sports Physiotherapy. Churchill Livinstone, Edinburgh.

Willoughby, D.S. and S. Simpson, 1998. Supplemental EMS and dynamic weight training: Effects on knee extensor strength and vertical jump of female college track and field athletes. J. Strength Condition. Res. A, 12: 131-137.