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The Effect of Eccentric Isokinetic Training at Various Positions on Concentric and Eccentric Strength of the Quadriceps

Hsiou-An Hu, Choon-Khim Chong, May-Kuen Wong

The purpose of this study was to evaluate the effect of quadriceps isokinetic eccentric training program at the strength of both concentric and eccentric strengths, as well as for the different eccentric training positions. Fifty-two normal subjects (26 male and 26 female), aged 21-32 year, were randomly assigned to a control group and two treatment groups. The first treatment group (n=18) trained in the sitting position and the second treatment group (n=18) trained in the supine position. They received quadriceps isokinetic eccentric training 3 times/week for 8 weeks. The control group (n=16) did not train but was tested at the same time as the treatment groups. Average force (in Newtons) of 3 concentric and of 3 eccentric quadriceps contractions on the KIN-COM dynamometer at 60, 120 and 180°/sec was evaluated at the initial visit (pre-test) and two days after the last training session (post-test). Results showed that the treatment groups increased significantly ($P<0.05$) in eccentric and concentric force at all test speeds with interaction effect between position and mode. However, eccentric isokinetic training of the quadriceps at 120°/sec is not mode specific for 60°/sec, 120°/sec and 180°/sec; and also not speed-specific for 120°/sec, 180°/sec. Different training positions of quadriceps at eccentric contractions make no difference in strength gains. There was no complaint of post-exercise soreness in this study through adequate warm up and cool down program in every session of training or evaluation.

Key words: isokinetic exercise, eccentric isokinetic contraction, quadriceps

INTRODUCTION

The principle function of skeletal muscle is to exert a force through a joint. Current research classifies muscle work under three distinct functions: motor, stabilizer, and shock absorber [1]. The conventional methods used to increase muscle strength in rehabilitation setting involves the use of isometric, isotonic, and variable resistance exercise. With the development of computerized technology, computer-assisted isokinetic dynamometers are becoming widely used for training and evaluation of limb strength. Since 1982, the introduction of isokinetic

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dynamometers with eccentric loading capacity has inspired interest in the clinical use of eccentric training [2]. However, specific use of eccentric biased exercise in the clinical setting was uncommon until the early to mid-1980s [3,4].

Eccentric muscle action has been shown by many authors to be more efficient than concentric muscle action [1,2,5,6]. Eccentric contractions produce greater tension and use less oxygen than concentric contractions [1,2,6]. Velocity of contraction is one of the factors responsible for tension development. Most of the researchers have reported that as velocity of exercise increases, the maximum concentric force decreases whereas the maximum eccentric force either increases or diminishes slightly [7,8]. Several studies have shown that eccentric strength improves with eccentric training and that concentric strength increases after concentric exercise [9,10,11,12,13]. Although many studies have been done, none of the studies have examined the position-specific effect of eccentric isokinetic training of the quadriceps.

The two hypotheses of this study are:

1) Different quadriceps eccentric isokinetic training positions will have different effects on concentric and eccentric strengths.
2) Both concentric and eccentric strength are improved by isokinetic eccentric training program.

REVIEW OF LITERATURE

From a mechanical point of view, muscle can be represented as a model with two components: 1) a contractile component (cc) and 2) a noncontractile component [1,3,6]. The noncontractile component includes a series elastic component (SEC) and a parallel elastic component (PEC). The SEC is composed primarily of muscle tendon. The connective tissue sheath and sarcolemma constitute the PEC, and the myofibrils constitute the contractile component [1,3,6]. Concentric and eccentric contractions involve different configurations of muscle tissue components. In concentric contraction, some stretching of the SEC occurs, but most of the force is produced by the actual sliding of the muscle fiber filaments past one another. During eccentric contraction, the muscle is lengthening as it contracts, which stretches the SEC and allows it to contribute to force production.

When performing an eccentric contraction, the noncontractile components contribute to the net force generated by the muscle so that less tension is required from the contractile component. Therefore, maximum force generated by an eccentric contraction will exceed that of concentric contraction for a given muscle. It demonstrates that eccentric exercise is a more efficient form of muscle activity [1,3,5], and, therefore, certainly important for use in clinical rehabilitation [3,4]. Several investigators have discussed the important role of eccentrics in rehabilitation and testing. Dean has encouraged the increased use of eccentric exercise [6]. Multiple studies have reported specific biased principles in the lower extremity [2,3]. Based on biomechanical and progressive principles, Curwin and Stanish describe a protocol that incorporates the interactive effects of limb speed and resistance loads to progressively train the tensile tolerance of tendon [3,4].

The force-velocity curve describes the relationship between the velocity of muscle shortening and force a muscle can generate. Researchers have found that concentric force decreases as velocity increases in both the upper and lower extremities [10-14]. Klopfer and Greij explained that faster speeds allow less time in which to recruit motor units for a strong contraction [15]. Therefore, as velocity increases, fewer muscle fibers contract and force decreases. Conflicting results of the force-velocity relationship of eccentric contractions appear in the literature. In the upper extremity, eccentric force increasing as velocity increases has been shown [7,14]. Several researchers found no clear difference in quadriceps eccentric force value between speeds [8,12]. Walmsley et al. suggest that the conflicting results of eccentric force-velocity relationship studies are due to the testing of different muscle group or are due to different velocities of contraction during testing [7].

Despite the reported gains in strength utilizing eccentric muscle training, caution is advised when performing eccentric exercise because it causes delayed muscle soreness as a result of muscle damage [1,2,9]. Abraham has shown that the exercise induced soreness may be related to disruption of the connective tissue elements in the muscle and/or their attachment [16]. Friden et al have shown that soreness is associated with bouts of eccentric contraction. With eccentric training, soreness decreases [9,17]. Therefore, it seems that eccentric contraction is capable of producing pathological forces within the unconditioned muscle, and that a period of eccentric training allows the muscle to better withstand these potentially injurious forces.

MATERIALS AND METHODS

*** Subject**

Fifty-two volunteers (26 male and 26 female), ages 21 to 32 years were paticipated in this study. Subjects were free from any previous joint or muscular pathology. The subjects agreed to refrain from conditioning or weight training programs while participating this study. The subjects were randomly divided into three groups based on their availability to participate in the eight-weeks training program. Group Supine (18 subjects) trained eccentrically in supine position, Group Sitting (18 subjects) trained eccentrically in sitting position and Group Control (16 subjects') did not receive any training. All participants signed a statement of informed consent.

*** Equipment**

A computer-assisted KIN-COM dynamometer was used for all testing and training sessions. The machine is hydraulically driven and controlled by a micro-computer. The KIN-COM has been shown to be a reliable and valid machine for testing and training [18].

*** Testing Procedures:**

One week prior to training, each subject's dominant leg was tested concentrically and eccentrically at speed of 60°/sec, 120°/sec, and 180°/sec. The dominant leg was identified as the leg the subject would choose to kick a ball. Prior to KIN-COM testing, each subject completed a 5 minutes warm-up on a static bicycle. Each subject was tested in the seated position on the KIN-COM with the back full supported and the hip in 80-85 degrees of flexion (Fig. 1). Trunk strapes and thigh straps were used for stabilization. Subjects were instructed to cross their arms in their lap during testing. The axis of the KIN-COM level arm was aligned with the lateral epicondyle of the femur. The level arm pad was positioned anteriorly on the skin, immediately above the malleoli, and secured with a velco strap that encircled the leg. At each velocity, for each mode of contraction, the subjects perform four sub-maximal warm-up contraction and one maximal warm-up contraction. The five warm-up contractions were followed by a 1 minute rest. Next, the subject performed three maximal concentric and three maximal eccentric contractions. All the tests were done by the same examiner and verbal encouragement was given during the test. After KIN-COM testing, the subjects completed a 5 minutes cool-down on the static bicycle followed by ice-pack for 15 minutes. All subjects were retested using the above protocol two days after the last training session. For each test, gravity correction was done.

*** Calibration and Parameters**

The dynamometer was calibrated before training and testing each subject. The subject's range of motion was limited to an 70° arc (ranging from 80° to 10° of flexion). The minimal force requirement was set at 20 Newtons (N), requiring subjects to generate at least 20N of force to activate the level arm. The maximal force limit of the machine

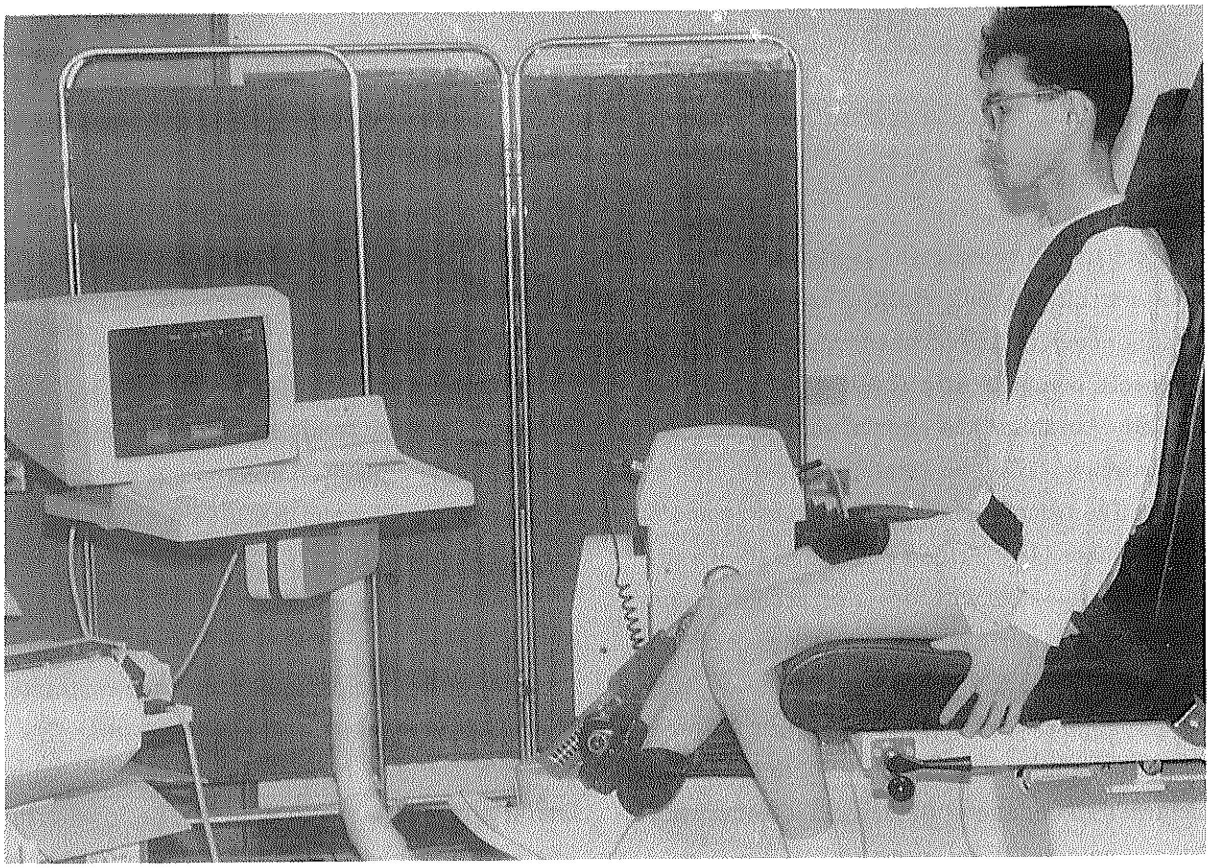

Fig. 1. Figure illustrated the subject was tested in seated position.

was 2000N.

*** Training**

All training groups exercised their dominant quadriceps three sessions a week (Monday, Wednesday, Friday or Tuesday, Thursday, Saturday) for consecutive eight weeks. The first treatment group trained the quadriceps in the sitting position the same position described for the testing session (Fig. 1).

The subjects in the second treatment group were positioned supine with the knee to be trained flexed to 80° to begin the training (Fig. 2). Subjects were stabilized with a belt across the pelvis, a velcro strap securing the upper back to the table, a velcro strap just proximal to the knee being trained, and a velcro strap securing the leg to the shin pad and level arm of the KIN-COM. All contractions in the training regimen were performed eccentrically at 120°/sec. Warm-up contractions consisted of four submaximal contractions and one maximal contractions, followed by a 1-minute rest. Next, the sub-

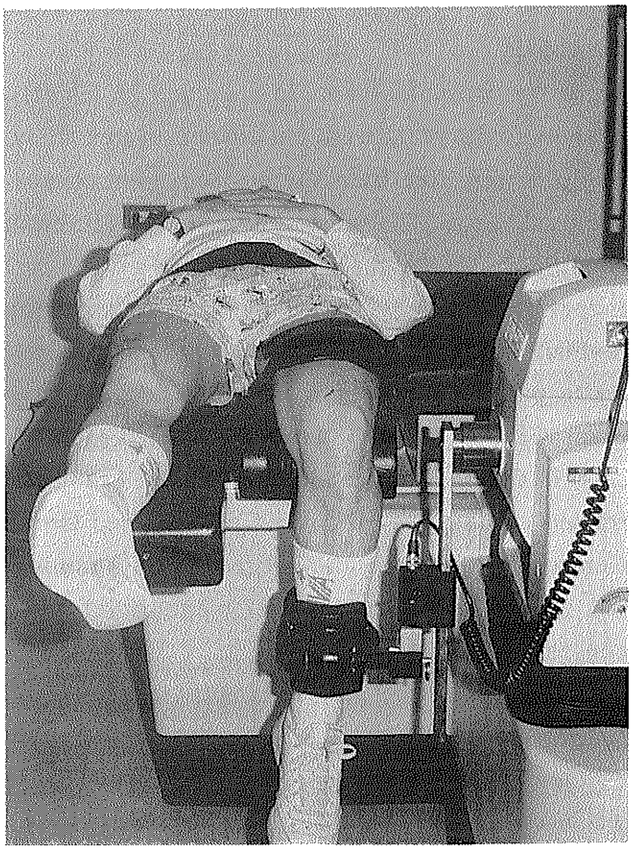

Fig. 2. Figure illustrated the subject was positioned in supine during training session.

ject performed 3 sets of 6 maximal contractions with verbal encouragement from the tester. After each training session, an ice-pack was applied to each subject for 15 minutes as a cool-down phase.

*** Data Analysis**

Initial characteristics of the three groups were analysed by ANOVA. No further adjustment between the three groups were made.

The change in force from pretest to postest, was analysed in terms of percent force change in force, that is percent force change = [(posttest force - pretest force) / pretest force] × 100%. For both the exercise groups and control group, t-test were used to determine if there was a significant ($P<0.05$) percent force change at each speed and mode combination between the groups.

A repeated measure ANOVA was used to determine if there were any significant ($P<0.05$) interaction effects between position, modes of contraction and speed.

A multiple comparison (Student-Newman-Kuels) test was then performed to determine if there was a significant difference ($p<0.05$) in percent force change across the three speeds and positions at each mode of contractions.

RESULTS

Descripitive statistics of each group are present in Table 1 and 2 for the following values: age, height, weight, and average pretest force at each speed and mode, there was no significant difference in the initial characteristics of the three groups ($p>0.05$). Table 3-5 shows the results of treatment groups with percent change in force significantly increased in force at all test speeds at both supine and sitting ($p<0.05$). Table 6 showed eccentric force

Table 1. The comparison of age, body weight and body height in 3 groups

Variables	Control (n=16)	Supine (n=18)	Sitting (n=18)	P
Age (yr)	26.75± 3.07	26.78± 3.44	27.39± 3.52	0.8164
BW (kg)	58.22±11.54	58.83±10.79	55.89±11.26	0.7104
BH (cm)	164.88± 8.69	164.39± 8.50	163.17± 9.59	0.8464

Table 2. Average pretest force (in Newton) of the control, supine and sitting groups at each speed and mode

Variables	Control (n=16)	Supine (n=18)	Sitting (n=18)	P
Concentric				
60°/sec	465.36±121.36	453.92±135.79	417.49±122.10	0.5141
120°/sec	387.03±118.51	382.58±129.75	352.23±103.83	0.6389
180°/sec	333.66±106.43	327.39±114.22	308.75± 94.49	0.7703
Eccentric				
60°/sec	592.28±185.51	539.48±174.83	549.66±175.94	0.6658
120°/sec	657.98±207.27	605.10±213.04	604.69±163.37	0.6666
180°/sec	680.67±199.47	623.63±203.77	580.46±153.35	0.3020

Table 3. The percent force change of the control group

mode and speed combination	mean % change	sd	t	P
CON 60°/sec	1.77	4.38	1.61	0.12
CON 120°/sec	1.18	4.65	0.61	0.55
CON 180°/sec	0.49	4.50	1.01	0.32
ECCE 60°/sec	0.81	5.31	0.49	0.63
ECCE 120°/sec	0.41	3.36	0.43	0.67
ECCE 180°/sec	1.22	2.56	1.90	0.08

CON: Concentric
ECCE: Eccentric

Table 4. The percent force change of the supine group

mode and speed combination	mean % change	sd	t	P
CON 60°/sec	9.28	9.11	4.32	0.0005
CON 120°/sec	10.53	7.68	4.17	0.0006
CON 180°/sec	10.95	9.81	5.82	0.0001
ECCE 60°/sec	42.07	42.76	4.37	0.0004
ECCE 120°/sec	37.24	36.13	4.73	0.0002
ECCE 180°/sec	31.97	22.06	6.15	0.0001

CON: Concentric
ECCE: Eccentric

Table 5. The percent force change of the sitting group

mode and speed combination	mean % change	sd	t	P
CON 60°/sec	21.39	21.33	4.25	0.0005
CON 120°/sec	17.33	18.40	7.93	0.0001
CON 180°/sec	12.39	16.13	4.00	0.0009
ECCE 60°/sec	51.74	27.67	6.93	0.0001
ECCE 120°/sec	38.27	23.43	3.26	0.0046
ECCE 180°/sec	40.70	28.18	6.13	0.0001

CON: Concentric
ECCE: Eccentric

Table 6. The eccentric percent force change minus concentric percent force change at each speed for exercise group

Speed	Mean	SD	t	P
60°/sec	31.57	34.07	5.56	0.0001
120°/sec	23.83	28.64	4.99	0.0001
180°/sec	24.66	23.05	6.42	0.0001

Table 7. Repeated measure ANOVA to determine interaction effects between the parameters

Parameter	df	F	P
Position (P)	2	19.77	0.0000*
Concentric/Eccentric (C)	1	34.22	0.0000*
Velocity (V)	2	3.98	0.0218*
Interaction:			
(a) P X C	2	8.24	0.0008*
(b) P X V	4	1.36	0.2529
(c) C X V	2	1.98	0.1436
(d) Px Cx V	4	1.93	0.1110

* significantly different at P<0.05

change is greater than the concentric force for both treatment group. The control group showed no significant increase in force at all test speeds at the end of the study period.

The repeated measure ANOVA analysed the interaction effects between position, mode and speed. An interaction effect was found between position and modes of contraction (Table 7). The repeated measure ANOVA showed no significant difference between concentric percent force changes at different test speeds (Table 8). The Student-Newman-Kuels multiple comparison indicated that the two treatment groups have significant improvement in concentric strength by comparison to the control groups. However, the difference in concentric strength gains between these two treatment groups is not significant (Table 9).

Table 8. Repeated measure ANOVA to determine the effect of position and velocity in concentric force change

Parameter	df	F	P
Position (P)	2	13.74	0.0000*
Velocity (V)	2	1.22	0.2998
interaction:			
P X V	4	1.17	0.3269

* significantly different at P<0.05

Although two treatment groups have significant improvement in eccentric strength when compare to the control groups, the difference between these two treatment groups in different training positions is not statistically significant (Table 10, 11). Table 12 showed that there were significant difference between eccentric percent force change across the three test speeds. The greatest eccentric gain occurred at 60°/sec rather than the training speed (120°/sec).

Table 10. Repeated measure ANOVA to determine the effect of position and velocity in eccentric force change

Parameter	df	F	P
Position (P)	2	15.73	0.0000*
Velocity (V)	2	4.78	0.0105*
interaction:			
P X V	4	1.82	0.1303

* significantly different at P<0.05

Table 11. Student-Newman-Kuels multiple comparisons between position in eccentric force change

	% difference	q-statistic	P
sitting vs supine	43.59 vs 37.09	1.16	>0.05
sitting vs control	43.57 vs 0.81	7.42	<0.05
supine vs control	37.09 vs 0.81	6.30	<0.05

Table 9. Student-Newman-Kuels multiple comparison between different positions in concentric force change

	% difference	q-statistic	P
sitting vs supine	17.04 vs 16.25	0.37	>0.05
sitting vs control	17.04 vs 0.82	7.40	<0.05
supine vs control	16.25 vs 0.82	7.04	<0.05

Table 12. Student-Newman-Kuels multiple comparisons between velocities in eccentric force change

	% different	q-statistic	P
60° vs 120°	32.72 vs 26.26	3.71	<0.05
60° vs 180°	32.72 vs 25.53	4.13	<0.05
120° vs 180°	26.26 vs 25.53	0.42	>0.05

DISCUSSION

The results of this study demonstrate that isokinetic eccentric training of quadriceps at 120°/sec significantly increases both eccentric and concentric force at 120±60°/sec. However the finding of this study is not mode-specific, agrees with several eccentric training studies [9,12]. According to the observations of Duncan et al the effect of quadriceps eccentric isokinetic training for 6 weeks showed mode-specific. For this study, the duration of training was 8 weeks, the result was different. Besides, the subject in this study are sedentary person, and the concentric strength of the quadriceps still have a greater potential for strength gain. More test sessions or longer duration of training in future study may verify the effect of training period.

The force produced by skeletal muscle is dependent on the length of the muscle at any instant in time. Eccentric muscle training requires a subject to resist an applied load while the muscle fibers are being stretched. In this study, the different training position of quadriceps make no effect on the strength gains, probably due to the 3 heads of quadriceps, except the rectus femoris, not act as two joints muscle. The effect of training at different positions will be different for the true two joints muscles such as hamstrings.

The eccentric isokinetic training of the quadriceps at 120°/sec is not velocity-specific in this study is compatible with other researcheres [8,10]. The speeds outside of this velocity range should be further investigated especially for the high speed training.

Eccentric muscle contractions are inherent in functional and athletics activities, but are often overlooked in the traditional rehabilitation regimens. Lengthening tension is needed to facilitate the return of sacromeres and the subsequent length-tension relationship inherent to regain normal function in the atrophied muscle following immobilization [1,2,6].

One of the main disadvantage of eccentric muscle contraction is the problem of post-exercise muscle soreness. In this study, adequate and appropriate warm-up and cool down was given to the subjects before and after every training or evaluation session. There was no complaint of post-exercise soreness from the subjects.

In clinical, it is more common for the injuries occur in the eccentric phase of contraction. It seems that eccentric training at higher speed may provide a means of strengthening the series elastic component of muscle via progressive overload principles [3,4]. Eccentric training can produce higher tensions in muscle than concentric training which may provide a more effective stimulus for the improvement of muscular performance, as well as for the tension-generating capacity of the connective tissue, especially at the musculotendinous junction. This improved ability to resist high forces may reduce the risk of injury to the muscle. However, further research on larger populations, train at different speed or duration should be done before clinical implication.

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不同姿勢下對股四頭肌做離心收縮運動訓練對股四頭肌之向心及離心收縮之影響

胡秀安　張春琴　黃美涓

本研究計劃的目的是探討在不同姿勢下對大腿的股四頭肌作離心等速運動訓練(eccentric isokinetic training)，對股四頭肌離心收縮力(eccentric strength)及向心收縮力(concentric strength)之影響。五十二位正常的受試者，年齡層在21～32歲，被隨機地分配至對照組(16人)，實驗組A (18人)和實驗組B (18人)。本研究是藉由KINCOM Isokinetic Dynamometer來進行受試者慣用腳股四頭肌肌力之評估與訓練。實驗組A採坐姿訓練，實驗組B採仰躺(supine)的姿勢，對照組則不接受訓練。在開始訓練的前後，所有的受試者各接受一次股四頭肌肌力評估。在評估時，分別將角速度設在每秒60度，120度及180度，每一個角速度下受試者需完成三次最大離心收縮及三次最大向心收縮。分配至實驗組的人需接受為期八週，每週三次之股四頭肌之離心收縮運動計劃。在訓練過程中，每一次受試者都需完成18次的離心收縮(將角速度設在每秒120度)，分成三梯次完成(3 sets, 6 repetitions/set)。對照組雖然沒有接受訓練，但二次評估中間需間隔八週。

本研究的數據經由統計分析(Repeated measure ANOVA)，其結果顯示：

1) 實驗組A及B在訓練前後股四頭肌肌力之變化，不論是離心收縮力或向心收縮力均有顯著的肌力增強，與對照組間之差具有統計上的意義(P<0.05)。
2) 對實驗組而言，以坐姿或仰躺接受訓練兩組間股四頭肌肌力增加的差異並沒有統計上的意義。
3) 在不同的角速度下相比較，實驗組(A, B)之股四頭肌離心力增加之差異以每秒60度增加的比每秒120度及180度為多，且有統計上的意義；但120度及180度間之差異則沒有統計上的意義。
4) 實驗組向心力之增加在不同角速度上的差則兩組之間未達統計上的意義。

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